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Familiarization:

An Approach to Multidisciplinary Design

by

Ernest Baraniecki

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Abstract

This thesis presents the development and application of the familiarization approach to multidisciplinary design. The familiarization approach enables an engineering designer to enter a client environment that is foreign to the engineer. The engineer develops a sense of understanding of these extra-industrial environments by establishing a multidisciplinary platform, identifying the users, conducting a needs assessment, translating the user languages, abstracting, applying constrained creativity and formulating the real problem statement. A well executed familiarization phase, allows the designer to actualize a solution most suited to the client-user's true needs.

The thesis will demonstrate how familiarization was applied to an actual project. The design project undertaken addresses the wheelchair instability issues experienced at a long-term care home. The familiarization approach had to be developed and implemented to solve the right problem and address true user needs.

Table of Contents

List of Figures

Chapter One
Introduction

The purpose of this section is to:

- Introduce the state of mechanical engineering design education.
- Present the focus of the thesis.
- Outline the scope of the work involved in my project.

Engineering Design Education

Recently, the University of Calgary Department of Mechanical Engineering has placed more emphasis on design-related courses as part of its curriculum. Design is no longer treated as a self-explanatory, self-evident, 'well-known', specific and procedural task. Design is now seen as a multifaceted and creative problem-solving activity that promotes the application of mechanical engineering knowledge.

This contemporary approach to design education in engineering is motivated by the concerns of various academic and engineering bodies. For instance in 1997 the Canadian Engineering Accreditation Board called for a more "creative, iterative and [...] open-ended" approach to design education that should culminate in a significant design experience. More pressingly, NSERC has decried the shortage of design engineers who "have the skills and knowledge to make innovation happen." Pointing out that "design engineering is the essence of what engineering is all about," NSERC argues that the need for improved design engineering education in Canada is urgent.

To what can this shortage of innovative design engineers be attributed? A major source for the lack of emphasis on engineering design education is the Grinter Report of 1955. The Grinter Report was intended to establish a provisional engineering curriculum. The authors of the report expressed what they believed were the most important topics to be included in engineering education: the scientific and mathematical aspects of engineering. This emphasis on a mechanistic view of design driven by scientific and mathematical aspects of engineering necessarily neglected a more creative and innovative problem-based approach. Although no university was obligated to use the Grinter Report as the model for their engineering curriculum, most engineering curricula did reflect the values propounded in the Grinter report.

It is ironic that while engineering curricula were increasingly driven by linear, monodisciplinary and deterministic approaches to design education, industry was championing a more generalist and multidisciplinary approach. For instance the implementation of systems engineering, design-for-manufacturability and concurrent engineering demanded designers who were proficient at a variety of facets related to engineering and who could work in a multidisciplinary context with a variety of non-engineering professions.

The possible rewards of using such a multidisciplinary and generalist approach was vividly brought home to me when I was faced with a design challenge in the form of the graduate design project. Since this project both generated the core questions and allowed me to develop and articulate the answers that form this thesis, it is appropriate to provide the following summary of the project.

In December of 1996 W.K. Dickson, an advisor and benefactor to the Bethany Care Society submitted a proposal to the Mechanical Engineering Department at the University of Calgary. In it, Mr. Dickson identified a problem with wheelchairs as used by the residents of the Bethany Care Center. Both the Bethany Care Society and the University of Calgary agreed that there was enough merit to warrant a further investigation of the problem. The University of Calgary, University Technologies International and the Bethany Care Society entered into an agreement to investigate the area of the 'passive wheelchair braking system'. The project was to be undertaken by myself, a mechanical engineering graduate student, as part of my master's thesis in the field of design. The duration of the project was expected to be two years divided into one-year terms. In the first term the investigation of the problem was to be carried out and the findings was to be presented to the members of the Bethany Care Society. It would then be up to the Bethany Care Society to decide whether to pursue the project into the second year. The second year of the project was to be designated for the design and development of a solution.

At the time that Mr. Dickson initiated the proposal, it was felt that the problem with wheelchair accidents was related to the park brake that is an integral component to every manually propelled wheelchair. Mr. Dickson encouraged the idea of designing and developing a park brake that would automatically engage and release. According to Mr. Dickson, such a device would contribute to his primary objective of "Improving the Quality of Life of the Seniors and Disabled Residents of the Bethany Care Center." By reducing accidents and ensuring the safety of residents and staff. A solution to a project of this nature would integrate the needs of the administration, residents, caregivers and therapists.

As I became more involved with the problem, it became evident that input from these other disciplines was necessary in order to solve the problem at hand. For instance many accidents were identified by the occupational therapists. It became evident that simply approaching the problem as one intrinsic to the mechanics of the wheelchair itself would not result in a satisfactory solution. I not only sought input from the staff at Bethany, but also found many insightful ideas from reading in other fields such as industrial and environmental design, psychology, architecture, management, manufacturing and marketing. As the project progressed, design and administrative techniques borrowed from the fields of industrial design, therapy, management, etc. were employed to develop an approach tailored to mechanical engineering design.

Throughout the project, it was necessary to rethink deterministic models of the design process in favor of concepts that may more effectively address the assessment of problem needs and goals, and solution generation. Many of these coalesced around the theme of what can be called familiarization. Fields such as industrial design and engineering use familiarization as a technique to better understand the user environment. In this case I had to familiarize myself with not only the wheelchair and the environment it was used in, but also the circumstances in which accidents occurred. This contextualized analysis of the problem eventually allowed me to identify the exact problem that needed to be solved. Other concepts generated in my rethinking of the design process come under the rubric of creativity. The situation warranted creativity in both the formulation of the problem and the framing of the solution. Therefore the importance of tangibly integrating creativity in both problem and solution phase was crucial to my success in the project.

In reflecting upon this project, I realized it offers a unique opportunity to grapple with the more innovative aspects of design engineering called for by NSERC and CEAB. Specifically, it allows for the generation of concepts that can be potential topics for the development of a new program of engineering design education. These concepts revolve around implemented definitions of creativity and familiarization and the integration of both these concepts into the solution, or what I term the actualization, phase of design.

It is the intent of this thesis to define and develop these topics for the benefit of potential engineering design educators. The following is a description of the purposes of the major chapters:

- Design: Since the 'controversial' word ***design*** will be used through the thesis, it is appropriate for the author to make his views on the subject of design known to the reader. It is intended for the reader to appreciate the challenge in describing the term design, as well as comprehending the importance of creativity in design.
- Creativity: One of the most important intrinsic components of engineering design. Without creativity there wouldn't be any design. This chapter illustrates the

complexity of creativity, emphasizes its importance, proposes an understanding of its mechanism, and instills in it credibility as a tangible phenomenon that must be applied to an engineering design problem.

- Familiarization: This is the crux of the thesis. This chapter discusses all the issues involved in the familiarization approach as applied to engineering design. It not a prescriptive procedure, it is the summation of all issues that an engineering designer must develop and apply during familiarization. Not only is the theory of familiarization examined but also its realistic application on my project.
- Actualization: This is really the second major phase of engineering design. Actualization contains all traditional tasks of engineering design. During the former approach to engineering design education the familiarization was completely neglected and the student jumped directly in actualization. This chapter stresses that familiarization lays the foundations to actualize the solution. Since the focus of the thesis is primarily familiarization, actualization is only developed to the point of conceptualization.

A thesis of this nature offers a unique opportunity to explore the process of innovative engineering design from both a theoretical and practical perspective.

Chapter Two
Introduction to Defining Design

Design has many meanings ranging from planning to drawing. Furthermore, the meaning of design can vary by discipline. However, the meanings of design in the disciplines of engineering, architecture and industrial design seem to share a common denominator. Their intention is to provide a 'solution' that caters to the needs of the client. The solution, which could be a product or a service, is preferably reached by executing a plan or a technique. But not every field that has techniques, plans, and solutions uses the word design, for example finance, accounting, law and medicine. The term design is usually used for architects, interior decorators, hair stylists, industrial designers, and engineers.

What is design? Can it be defined? What activities or objects can be said to comprise design? Are people who claim to be designers, really designing?

The following is a brief overview of engineering design. It will present the facets of design within the context of contemporary mechanical engineering. These facets include the engineering design stages of problem formulation, conceptualization, embodiment and detail design. This simplified profile will ultimately be the starting point for the introduction of newer engineering design concepts that will be explored in this treatise.

The Process

The two most common approaches for presenting the engineering design process are prescriptive and descriptive (Waldron & Waldron, 1996). Both have similar components but are different in their nature of proceeding.

The Prescriptive Design Process

The prescriptive process is commonly presented in undergraduate engineering design courses (Singh, 1996, Ullman, 1992). The process entails the distinct stages of problem statement, conceptualization, embodiment, and detail design, in a linear systematic fashion. The designer is expected to follow this procedure to produce a solution to the given design problem. Do to the complexity of real life design situation, this type of model is rarely executed sequentially.

The Descriptive Design Process

A more realistic design process is known as the descriptive process (Hyman, 1998, Waldron & Waldron, 1996). In this model the stages of design are identified after the designer reaches the solution. The designer doesn't follow any specified path but his/her actions are directed toward achieving a solution. Because the stages of problem formulation, conceptualization, embodiment, and detail are usually interrelated and imprecisely defined, the descriptive process is usually iterative and unique to each designer and problem.

Problem Formulation through the Identification of Needs

The fundamental component of any design process is the presence of a problem. If there was no problem to solve, any activity would be recognized as 'making' rather than 'designing' (Pye, 1970). The problem is a derivative of the unsatisfactory conditions, or 'needs', of the potential user and client. At the root of any design problem lie needs. Needs are the impetus that can ignite and drive any design problem. Without a need there would be no problem to solve, there would be nothing to design.

A need, in design terms, is a brief description of an unsatisfactory condition. The potential users/clients approach the designer because something is bothering them. Every user/client has some set of unsatisfactory conditions, however strangely enough, not everyone is fully aware of the true nature of their unsatisfactory conditions. Pitts (1973) cautions that this may be because customers may not have the knowledge to define the needs specifically. They either may be accustomed to their unsavory situation or they may have falsely perceived unsatisfactory conditions. It is therefore the role of the designer to *find the user's/client's true unsatisfactory conditions (needs).* Finding these needs is known as need assessment and is an absolutely crucial activity of any design project.

Many authorities on design believe that the need assessment process begins by identifying the origin of needs. Needs can arrive from a variety of sources ranging from the inadequacy of existing products to changing social conditions. Hubka (1996) says that needs arise from wanting to achieve a result from a current state of affairs. The obvious example would be if a given product or service does not produce a desired result. A satisfactory product or solution would then be needed. Shoup (1981) states that engineers do not create needs (just like doctors do not create illnesses), and that designs are responses to social needs (a cause and effect relationship). Birmingham (1997) claims that needs from society and individuals are derived from changes in influencing conditions. The changes in these conditions may be of a social, technological, economic or geographic (Gregory, 1966) nature, or a combination of any of these factors.

Due to changes, new needs are part of a cycle as opposed to a linear cause-effect relationship. The cycle starts with a new need that evolves into a new design. The new design eventually becomes obsolete due to a change in technology (Ullman, 1992). The change in technology warrants new needs and the cycle repeats itself. Historically this cycle of product production, implementation and obsolescence is accelerating. Products in the Japanese electronics market complete this cycle in approximately 6 months. This indicates that needs are being generated at an increasing rate.

The main tool (or process) for finding these needs in industry is through marketing.

Marketing can determine whether there are needs for a product and whether these needs exist or are temporarily nonexistent. An example of a successful product whose needs were apparently nonexistent before its design is the automatic (photosensitive) faucet. Ullman stresses that the majority of needs are derived from the market itself, that is to say from customer wants. Other needs can evolve from the design of a higher order system. If for example a large-scale system such as a space shuttle is being designed, there would be the need to design several significant components such as rocket boosters. Needs begin the process of generating ideas (i.e. the outcome of the need assessment), though there are rare instances were an idea gave rise to a need. A hula-hoop is an example of a need originating from an idea (Ertas, 1993).

Once the needs have been identified, an initial problem can be formulated. The problem is composed of a system of statements consisting of the goal, the objectives and the constraints (Hyman, 1998). Their definitions are as follows:

- *Goal*: General statement that responds to the given need; sets direction for solution actualization.
- *Objective*: Statement of functionality and main criteria of the potential solution.
- *Constraint*: Specific design attribute that must be met by the product.

The *goal* comes in two forms: macroscopic and microscopic. The macroscopic goal is the major and general purpose of the user/client environment. The mission statement of an organization or corporation qualifies as the macroscopic goal. Any activity in pursuit of the solution of the problem must be performed under the umbrella of this goal. An organization or an environment can have many needs and problems. The microscopic goal is the response to a particular need. The need can give rise to a plethora of solutions to address it. The microscopic goal sets the direction for the solution. The typical application of the design engineering goal has 'microscopic' connotations (Hyman, 1998).

The *objective* is a set of statements that indicate the functionality and main criteria of a solution that would pacify the identified need. Functionality answers the question: "What must the solution do?" (Hyman, 1998). It doesn't indicate how to do it nor does it describe the how the solution looks or what it is. Criteria are quantifiable characteristics or requirements of design that are to be reflected by the solution. The user, client, and designer subjectively select the criteria. The designer can have a control over these requirements and interpret them subjectively.

The *constraints* are specific design characteristics that must be met by the product (Hyman, 1998). These rigid requirements are imposed on the designer by the user, client or external environment. The designer has no control or influence on these constraints. The solution must meet them or it is considered a failure.

Therefore the problem acknowledges a need, and identifies the functions, criteria and restriction considerations that a possible solution should have in response to the need.

It is important to note that the problem is a function of time. The details of the problem statements keep changing as more information is acquired. Therefore the problem is continuously refined. However if the need is stable, the fundamental aspects of the initially formulated problem should not change either. Only certain details of these statements can be incrementally varied, with each increment being lesser than the previous one. No problem could be comprehensively stated; the ultimate definition is asymptotic (Lawson, 1990).

Conceptualization

The conceptual design stage is an essential part of any design process. During conceptualization the designer generates ideas or concepts that could be developed to become the solution (Singh, 1996). The solution contrived during conceptualization is supposed to fulfill the given needs, demands, requirements and constraints (Hubka, 1996, Ullman, 1992). Most importantly the designer is encouraged to generate the solution creatively (Hyman, 1998).

Traditional engineering designers have developed techniques to generate concepts and to address the given constraints. These include functional composition assessments, feasibility studies (Singh, 1996, Woodson, 1966), patent searches, function-concept morphologies (Ullman, 1992), and various algorithmic approaches (Levary, 1988). 'Creativity techniques' are also described. For example Hyman (1998) presents a model of concept exploration, incubation, intimation and illumination.

Embodiment

The third stage of the classical engineering design process is the 'embodiment' of the concept. During this stage the concepts are laid out (Singh, 1996, Hubka, 1996). The ideas take form without specific detail. Activities associated with embodiment include critical assessment of the concepts, economic evaluation, error check, verification of all customer requirements, preparation of preliminary production documentation and design optimization. Upon finalization of this stage the idea will be mature enough to be documented in a fully detailed fashion.

Detail Design

Detail design generates all documents required for production (Singh, 1996). The potential solution must be presented in a form that will be used to manufacture it as a final product. The documentation will be as set of specification that include all parts, materials, dimensions, tolerances and manufacturing process to be used in the realization of the product (Ullman, 1992). Once the detail design stage is complete the design is ready to be produced.

Product

The product in general terms could be viewed as the object resulting from a process. But the specific definition of the design product asserts more than just an object. An engineering design product must be a solution to a design problem. The solution comes in form of an object or system of objects that are created and implemented to address the design need. The object could be an artifact, a deliverable, a manufactured entity, a 'mechanism' for changing a particular state of affairs, a document, a change in policy, a procedure, etc.

This object or set of objects must work effectively and realistically to solve the problem. This implemented solution is not an idea as a state in the designer's mind, but an idea in the state of existence. It must be actualized through a design process and implemented realistically.

Furthermore, Lawson (1990) observed that there are an inexhaustible number of different solutions and that there are no 'right' solutions. Since the problem is continuously modified as a function of the amount of information given, the number of possible solutions can never be precisely determined. Also, there are no absolutely correct solutions because no product can simultaneously satisfy all the given needs and requirements. There may exist a range of acceptable solutions that are selected by the user, designer or client. Any solution can always be improved; the designer must stop at some point due to limiting factors that can be temporal, financial, informational, or resourceful.

Essentially a product must solve the design problem by satisfying as many initial, current and potential needs as possible. It is also crucial that the product be implemented, effective and functional.

Relationship between Product and Process

Ideally the product is the ultimate outcome of an engineering design process. Most of the stages of a process are product oriented. These stages of design processes are typically derived from engineering methods and practices. Conceptualization, embodiment and detail design are well-documented stages in engineering design literature (Singh, 1996, Ullman, 1992, Hyman, 1998, Hubka, 1996, Roylance, 1968, Pitts, 1973). Since the discipline of engineering is primarily focused on achieving desired outcomes (products), most process stages are geared toward the *actualization* of a product.

Engineers have placed less emphasis on the earlier stages of design activity such as needs assessment and the early stages of problem formulation, since these stages are apparently not directly connected to the actualized product. Techniques and methods that could be employed in the early stages of engineering design have been significantly identified and developed by external fields such as marketing, management, and environmental design (Whetten, 1991, Keegan et al, 1995, Langon & Rothwell, 1985, Papanek, 1995). Marketing, for example, deals with all aspects intrinsic to the product, that stem from client needs, ranging from price to packaging (Bacon & Butler, 1981). Industrial design practice places emphasis on integrating factors into the design process that are part of the potential users' environment (de Noblet, 1993).

These approaches can offer the engineer an enhanced perspective while designing. If engineering designers are to approach design situations holistically, care should be placed in developing a strategy for the early stages of designing. Since contemporary engineering design literature has not adequately addressed these issues, it may be advantageous for engineers to borrow ideas from non-engineering fields. The disciplines of industrial design and architecture sometimes refer to the assessment of the user environment as *familiarization* (Walker, 1998). This in-depth approach to user needs can be adapted into a methodology for engineering designers to approach any design task.

Two Phases of Design Activity

The argument can be made that all engineering design processes can be contained in the two major design phases of: familiarization and actualization. Those stages that are typical of engineering design and that directly focus on producing a solution can be termed *actualization.* Those stages that deal with all facets prior to formal actualization and typically emphasized in other disciplines engineering can be referred to as *familiarization.*

These two phases differ primarily in their approaches to the solution. Actualization deals primarily with the solution. It is the compulsory phase where the solution to the problem is found, developed, produced and implemented. The engineering designer, by nature, wants to focus his efforts on solution development, therefore the actualization is seemingly the natural course of actions to take. Therefore actualization is the most common phase for any engineering designer to engage in.

In the familiarization phase a designer is not interested in finding a solution. For this reason, this phase is often neglected or partially incorporated into the actualization phase. This approach enables the designer to enter an unfamiliar client-user environment. Through this phase the designer develops an understanding of the clients and users, their environments, their needs, and knowledge related to their situation. The engineer can work with clients of a different industry, identify their needs, and solve their problems on their level.

The importance of the familiarization phase is commonly underestimated and misunderstood. It must be realized that the foundations of actualization are formed during familiarization. Ultimately, the true goal of the project is formulated that leads to a defined problem. The goal is the starting point for actualization that influences the potential solution and the nature of actions taken during the actualization phase.

Performer

In general 'design' terms a performer is an individual who participates in a process and contributes to the formation of the product. More commonly this performer is the designer but it can also be anyone who productively and effectively participated in the design process: user, client, consultation experts, manufactures, managers etc. Specifically, the chief performer in the design process is the designer.

The Performer as a Problem Solver and Creative Thinker

Once the design problem has been laid out, an effort must be made to solve it. Design and problem-solving are so closely tied that designing may be considered a special case of problem-solving (de Bono, 1970). Attempts have been made to layout a rational procedure for general problem solving. Whetten (1991) for instance suggests that the problems need first to be defined, alternative solutions generated and evaluated, and finally the solution should be implemented and followed up on.

Traditional approaches to solving problems assume that all information is available, therefore objective and logical steps can be taken to reach an optimal solution. It is also assumed that the rational approach can be applied either universally or to any problem in a given field.

However, the reality is that most design problems encountered are non-standard, meaning that no established procedure can be applied to provide a useful solution. Most problems are unique or original to the designer and the design environment. Adequate information for analysis is unavailable, incomplete or incorrect. The designer is forced to make decisions on a regular basis based on judgment and experience. Since the majority of the problem situation lends itself to subjective interpretation, no 'right' design can be reached. The solution to a design problem is meant to be the best one given the circumstances.

Due to the 'inconvenient' reality of design problems, successful designers often have to pursue alternative approaches to solve a problem. Usually this involves some degree of creativity (which will be discussed extensively is later sections of this thesis). Poincare (1924) proposed a 'creative' or alternate approach to problems solving:

- First insight: the recognition of the problem and the conscious commitment to solving it.
- Preparation: the development of an idea for solving the problem and a conscious attempt at a solution.
- Incubation: no conscious effort at finding a solution.
- Illumination: a sudden emergence of an idea.
- Verification: conscious development of idea into solution.

The above approach describes a sequence of phases based on observation of how, what may be considered 'creative' solutions, are derived. Realistically, there are no methods or techniques that can be used to solve a problem 'creatively'. If there were prescriptive creativity techniques, they could no longer be considered creative but rather procedures.

At each level of the maturity of the solution, there are obstacles to overcome. Problems contain hierarchies of obstacles that temporarily prevent the design to reach a target. These barriers or blocks have a wide range of sources: psychological, temporal, financial, social, legislative, limited resources, etc. Ottosson (from Eder, 1996) noticed that there are five types of individuals that attempt to overcome obstacles:

- The Deviator: Avoids the obstacle sets a new target.
- The Bypasser: Finds way around the obstacle to reach target.
- The Breaker: Does everything his resources allow to break the obstacle.
- The Indecisive: Isn't sure which way to go find a way around obstacle.

- The Seeker: Evaluates and rejects every idea to go around obstacle, but never gets anywhere.

The only two types of problems solver that manage to reach a target are the breaker and bypasser. The breaker will try to rigorously and systematically eliminate the obstacle in their way. This may be a drain on resources and the methods used are not always feasible. The bypasser on the other hand finds a way, a creative way, around the obstacle. Bypassers are the most successful problem solvers.

All effective long term problem solving requires planning. This means devising a strategy to know what must be done. The plan may be modified occasionally as more information is brought to the surface. Managerial skills are definitely an asset: organization of human and technological resources, feasibility studies, control and awareness of financial and temporal limitations, etc. Furthermore, the designer must see to it that the plan gets actualized from the beginning to the end. It is not enough to just get an idea or figure out a way past an obstacle, it must be realized. The purpose of the plan is to eventually converge on a solution to be implemented. As the plan is progressively administered, the solution goes through levels of maturity or concretization (Hubka, 1988). The final level of concretization is the manufactured, delivered and implemented product solution.

The Performer as a Designer

The performer in terms of 'designing' is the most difficult to discuss and the least studied in formal literature. The *performer* treated as the participant of a process is easy to understand, but what is a *designing performer*? How does someone know that he/she is designing? Isn't the presence of a process and a product sufficient to define the term *design*? No, Gasparski (1984) claims that the 'dimension' of the designer must be considered in the study of design.

The designer 'dimension' of the term design refers to the methodological orientation or 'attitude' the performer has. This orientation is a function of the performer's:

- Knowledge/Experience
- Environment
- Personality

Knowledge can be viewed as the summation of the performers practical and theoretical experiences. The more experienced an individual is, the more he/she is aware of techniques, processes and skills developed. With the abundance of specific knowledge a paradox forms: an increase of knowledge impedes creative thinking (Whetten, 1991). Knowledgeable people are aware of successful procedures orient their thinking within that particular framework. Less experienced individuals aren't aware of such processes and therefore are forced into deriving solutions alternate ways: creative ways. Consider the following situation: two individuals embark on the same design task. One individual is an experienced designer while the other is a novice. Both performers, independently, derive an implemented solution to the problem. For the novice this experience was rewarding, original and difficult. He derived and used methods previously unknown to him and enriched himself with lessons in problem solving. This person can be said to have an experience in design, and his solution was the result of *designing*. The expert came up with a better solution. But for him the experience wasn't so rewarding or enriching. He used methods, techniques and processes that were already known; he simply utilized existing knowledge. Very little creative thinking was employed because there was no apparent need. There were no obstacles to creatively overcome because all obstacles were well foreseen (due to experience) and those directions were never taken. The expert designer took safe, well mapped paths to reach the solution. In such a case the expert can't be considered to have *designed* even though he reached a better solution than the novice did. The expert, though, had the potential *to design* due to his knowledge in overcoming obstacles and going beyond his knowledge mental framework. These issues will be revisited and elaborated in the creativity section. The most astonishing point to be made is that in some cases the same actions may be performed on the same problem resulting in the same solution by two different people independently yet only one of these people actually *designed*! The one that designed had to derive, creatively, the methods that the other person knew full well. But since the experienced designer only followed proven methods for solving this particular problem, it can be argued that he 'made' the solution rather than 'designed' it.

Secondly the designing performer should be viewed within the context of his environment. Whether this environment is physical or social, it will have an influence on the type of actions the performer makes. Not only will the environment shape the subject intellectually, but culturally, psychologically, and perceptually. The designer develops attitudes, values, views, prejudices, and especially style. For instance: two designers working independently on the same project, will produce different results consistently. It could be observed that as the designers undertake more projects, certain facets of the product and the design processes used emerge that are intrinsic to that particular designer. This is a demonstration of the performer's *style*. The individual has developed an orientation or approach to design not only due to past experiences but also through their lifestyle, and environment. These factors are then reflected in the way the individual *designs* and the designed solution that he provides.

The environment and the experiences develop an individual's personality. Personality not only reflects style but also pride, ethics, morals, values, etc. One type of design that demonstrates the performer's personality is Spiritual Design (Papanek, 1995). Spiritual design means going beyond the assigned task for the good of the client or users. With references to morals and ethics, a designer selflessly does more work than is 'contractually' necessary, in pursuit of a 'just cause'. The 'spiritual' designer will not only consider the current needs of the user, but also the needs of the environment, needs of those that may be disadvantaged by the potential solution. He will put in the extra time, effort and resources (i.e. working for free) to benefit society and the environment. These types of traits are part of the designer's personality of which is eventually reflected in the designed solutions he provides.

To summarize, design must be viewed as the overall reflection of the designer's methodological orientation on both the process and product.

Creativity in Designing

A key component of the definition of the design process and the term 'design' is the presence of some elements of creativity. The term *creativity* gets just as carelessly used as the term *design*. For this reason a whole section of this thesis is devoted to the subject. For the sake of conciseness in defining the design process, creativity (within the process) must contain:

- Act of creation.
- Usage of original method.

Act of creation refers to the fact that something must be made or created. Creativity is not some mystical or abstract notion. It is part of reality and through it something must materialize. It is not enough for creativity to be only associated with generating an idea. That idea must be brought into existence. Moreover, whatever gets created must be useful and serve a purpose. Whether the solution is designed for functionality or appearance, it must do what it is supposed to do. It cannot exist only for its own sake but for the sake of someone or something else.

The second consideration of the term creativity is the method that was used to create something. A creative method is not just a way to generate an idea, but the derivation and administration of a way to achieve something. A characteristic of the creative method is that it is original or unconventional. There are three general cases when an original method could be used:

- Non-routine design: When an established method of solving the problem exists but performer uses a different method and reaches a solution.
- Innovative design: When no established method of solving the problem exists and the performer uses a different method and reaches a solution.
- Inventive design: When no established method of solving the problem exists and the problem was never solved before, and the performer is the first to find a method and reach a solution.

Each level is a form of creative design and each one is more sophisticated than the preceding level. In the first case a common problem exists, and so does a successful method for solving this type of problem. If the designer employs a new or different method to derive a functional solution then this is non-routine design. The solution derived could be the same if the established routine was used. But it could be different or better. The fact that novelty was used in the method makes this type of design creative. In the second case, a problem exists, and so do certain solutions, but there is no established routine method that is employed consistently. If the performer reaches a solution to this type of problem, using yet another method that he/she derived, then this is a case of innovative design. Innovation refers to the usage of elements of existing objects or methods for a different application. The highest order of creative design is inventive design. It occurs when a problem exists, but has never been solved by any method. If the designer is the first to solve this problem by any method, his solution will be an invention. Inventions are the first products of their kind in the market, moreover they can create their own markets.

If creativity is completely absent in the process, the activity can no longer be regarded as 'designing' but rather as 'making'.

Chapter Three
Creativity

Recently, engineering academic regulatory bodies, such as the CEAB and NSERC, require the development of engineering designers with "innovative skills" and "original ideas". They encourage engineering design products to be a reflection of originality, innovation and invention.

For this reason a different type of thinking is needed. The designer would have to rise above the mental norm in order to instill originality to his products. This may require attempting something by seemingly unreasonable, irrational or illogical means. Should this thinking and methods prove to be successful, then the designer is said to be *creative* or possess *creativity*.

Creative thinking is special because not only does it express innovation and originality in design work, but also it demonstrates the designer's ability to think on a unique level. Everyone has the potential and ability to develop creative expression, but the majority of the population tends to utilize "well established" methods and practices that are common in every day life. Since very few individuals in society truly function in a less well established mode of thought, creative people are not common.

So what is creativity? How does it work? How can people develop this type of thinking? How can it be applied to design? To attempt to answer these questions it is appropriate to explore a possible mechanism behind creativity. The ensuing creativity section will discuss this 'mechanism' and the fundamental nature of creativity.

Knowledge Templates

To understand how a designer thinks creatively, we must first understand how a human perceives information. One of the primary seminal authors on the subject of creativity is Edward de Bono. De Bono (1992) proposes a theoretical model of the manner in which a human brain accepts information and data at every moment of our lives. Although the exact neurological structures of information acceptance and processing by the brain are still debated, it has been proposed that the brain has developed a system of patterns for dealing with information. The principle resulting from this notion is that the brain only sees what it wants to see. Moreover the development of these patterns since birth has been crucial for survival of mankind.

These mental structures have been called paradigms (de Bono, 1992), frames of reference (Koestler, 1964), pattern languages (Alexander, 1977) or templates (Caswell, 1992). They will be referred to as knowledge templates in this thesis. A knowledge template will store and process given information. The brain has the ability to immediately select the appropriate knowledge template to match a given piece of incoming data. For example, when we see a wheelchair, we know it is used for seating and transporting the disabled. We know that we are not supposed to eat it or hang it on the wall. We know these things because we have developed a knowledge template that automatically deals with the piece of information called 'wheelchair'.

In such a way the brain takes all information and sends it to its 'appropriate' knowledge template. If a piece of information presents itself that is seemingly incompatible with the existing knowledge template framework, the brain then:

- Discards it; filters the information out or ignores it completely.
- Forces it into the 'best' possible knowledge template; this usually results in a misunderstanding, depending on the situation.

- Slowly starts developing another knowledge template (but usually based on existing templates) to accommodate more of this type of new information.

Figure 1 illustrates one way of looking at the mental framework of knowledge templates.

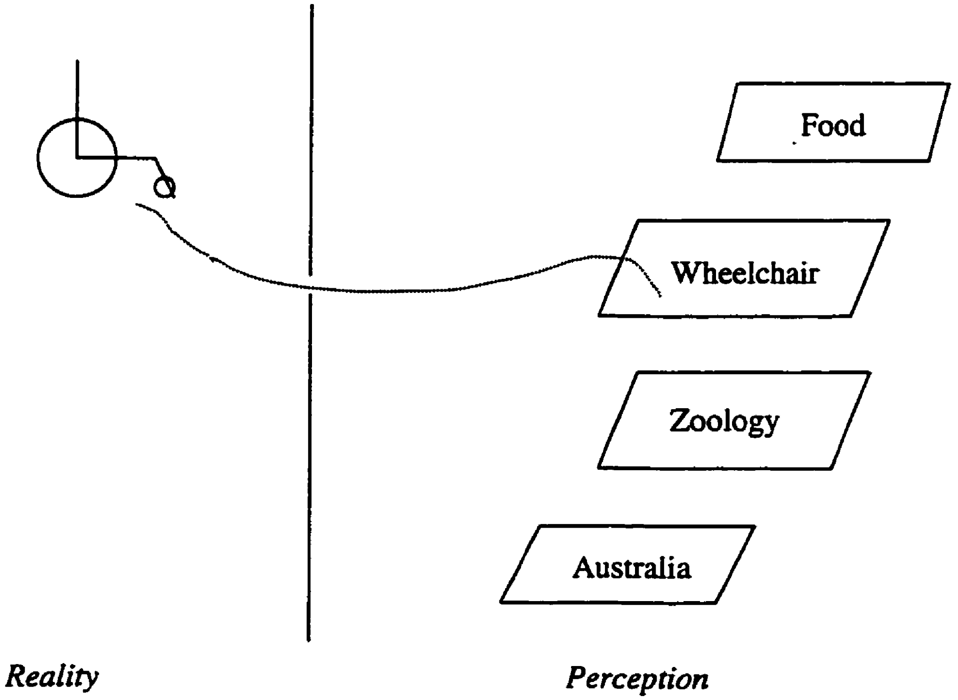

Figure 1: Application of Knowledge Templates

The above figure shows a simplistic view of these knowledge templates. The system of these templates, the neural network, is far more complicated and elaborate than this. The point is that the brain prefers to operate on patterns and 'logic' sequences. Even though this seems like a computer, the brain has one huge advantage over the computer. Namely, it automatically selects the appropriate template to process a given piece of information, whereas the computer must try every possibility before making the data-template match. In this way the brain 'perceives' reality through existing patterns.

Every human develops these knowledge templates from childhood. Everyone's template structure is different and the amount of knowledge for each type of template varies from person to person. The individuals environment and upbringing influences this structure.

Sometimes a particular environment can produce individuals with a similar knowledge structure. Thus the term 'common sense' can only be used colloquially.

Evidence of the brain's preference to patterns can be seen in everyday life and through experimentation. The brain doesn't function randomly. For example, if someone was to write down one hundred 1s and 0s as 'randomly' as possible they would fail. For a random set of one hundred 1s and 0s must contain 50% zeros and 50% ones, 25% 01 combinations, 25% 11 combinations, 25% 00s, 25% 10s, 12.5% 000s, and so on. The chances of someone producing a perfectly random series are extremely slim. If the conditions of randomness are not satisfied, it means the brain is attempting to develop a pattern or institute order in that set of numbers. Another example can be found in a game of billiards. It has been estimated that there are between 54 to 63 quadrillion possible shots in a game of pool (obviously this figure is based on the desired precision of ball position). However, as Martin (1993) points out, all these shots can be grouped into less that 100 types of shots (i.e. 100 knowledge templates to be developed). Each shot contains similarities that can be noticed and learned. Once a particular situation on the pool table can be identified, the brain finds a matching knowledge template containing information on how to administer the best shot. With time (learning) the following process happens instantaneously: situation of balls on table is matched with an appropriate knowledge template, the template sends information to the eye and hand on how to execute shot. Another example is chess. It has been calculated that there are ten to the power of ten to the power of fifty (i.e. 1 followed by 500 zeroes) chess moves (Kasner, 1989). No grandmaster ever memorized that many moves. Only certain sequences of moves are understood. Whenever a chess situation is analyzed, it is done by comparing it with a suitable known sequence of moves. Obviously, there usually isn't a perfect sequence to be administered given the situation, but some sequences are 'stronger' than others. The great chess players are those that can recognize a situation and apply the 'best' sequence of moves from their arsenal of chess templates.

There are the examples of patterns from everyday life. We recognize people audibly and visually by the rhythms and features that the brain accepts. If we are around a certain person for a considerable period of time, we develop a template of that person. Every time we see or meet a new person, our brain immediately tries to match this person with an existing template of a 'similar' person in our mind. The brain tries to match facial features, attitudes, actions, personalities, intelligence, etc. Therefore human beings by nature prejudge or stereotype others for better or for worse; usually we know if we are going to like/dislike a person or thing within 3 seconds. That is why in advertising (like television commercials) the message must grab the viewer's interest within three seconds, or it has failed. Another example of everyday patterns occurs during an argument between two people. Usually this is result of a disagreement over an issue. One of the main reasons for the disagreement is that both parties have different sets of knowledge templates. Therefore their perceptions of reality are different. Usually it is not a case of being 'right' or 'wrong' or that someone is at fault, it is a case of two contradicting perceptions. If the clashing knowledge templates are very strong and mature in each person's mind, a full agreement may never be reached.

There are countless similar examples. We experience this 'vision through patterns' all our lives. So why does the brain behave this way and not differently? According to de Bono (1992) the brain operates in codes and patterns as a means to our very survival. When we are children we learn at a faster rate than we will ever learn in our later lives. The brain biochemically develops neural networks (the templates) that store functional knowledge for life. If we didn't have these templates we would be confused whenever a piece of information presented itself. We wouldn't know what to do with food, or how to move from point A to point B, or recognise the functionality of objects encountered everyday. We would die like an unattended baby. Therefore these templates are a crucial component of the brain to ensure our survival.

The Genesis of Creativity

If we accept now that it has been established that the brain works in patterns and avoids any random actions, it can be seen that the brain is not creative all. Traditionally creativity has been regarded as a free, random, intangible, abstract way of thinking (although it will be shown that this is not quite true). Creativity starts by applying a way of thinking that breaks these existing patterns. It contradicts apparent paradigms, it seems illogical and unreasonable. Creativity requires an 'unnatural' way of thinking. De Bono calls this type of thinking 'lateral thinking' and Koestler coined the term 'bisociation' for it. The underlying principal behind this type of thinking is processing a packet of information on one template while applying knowledge from another template. Figures 2 and 3 illustrate de Bono's and Koestler's thinking models:

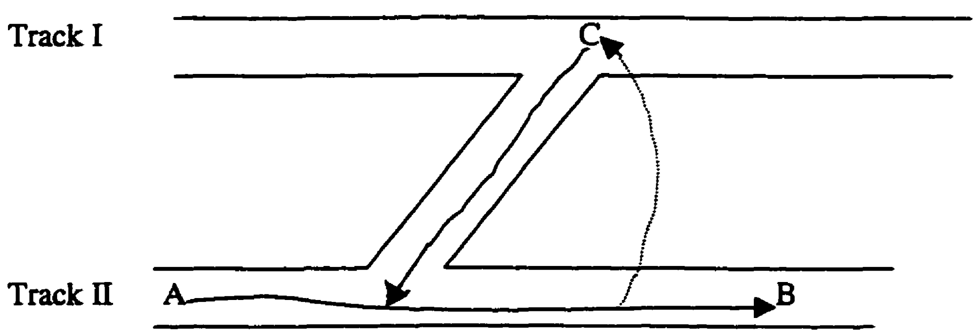

Figure 2: De Bono's Lateral Thinking

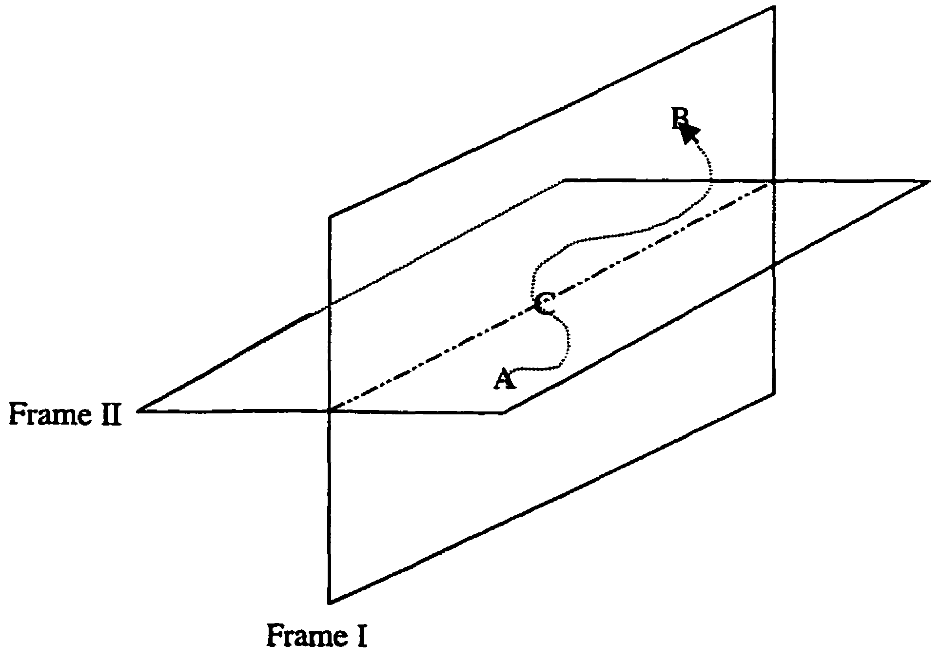

Figure 3: Koestler's Bisociation

De Bono treats the templates as tracks. Datum 'A' was automatically determined by the brain to enter Track II. From which it starts getting logically processed towards point B. The data processing is sequential and breaking this sequence is a violation of logic. In fact, every successful idea or notion that was ever derived seems to have been derived by logic in hindsight. This is not the case in many instances. Once the piece of data starts moving from state 'A' down Track II, there is no guarantee that it can ever reach state 'B' with the given knowledge contained in Track II. For this reason, lateral thinking can be employed. Lateral thinking is the unnatural act of 'leaping' to another track to bring in seemingly unrelated and irrelevant information to be processed by the original track. This 'lateral' leap has been depicted as a dotted line in figure 2. Information state 'C' from Track I is brought into Track II to be processed. Only then is it possible for data 'A' to be transformed into the final state 'B'. Assuming state 'B' is as successful concept that can be implemented as the solution to a given problem, one will believe that 'B' is the perfectly 'logical' solution to the problem. B is the 'obvious' solution and makes 'sense' because perception is only 'logical' in hindsight. Even though to reach 'B' a clear violation of the 'logical' process was committed.

Koestler calls knowledge templates: frames of reference. A piece of data, 'A', has been selected to enter Frame II. Let's assume that 'A' is a component of information related to a problem. Since Frame II is compatible with 'A', a solution to the problem should be found in Frame II. As 'A' starts its journey, (dotted line, in Frame II) looking for an answer, it may find nothing on the frame to solve the problem at hand. This could be due to insufficient knowledge contained in the frame. In such a case, a type of thinking called 'bisociation' may be used. If on Frame II, there exists a point 'C', which is a state of information, and if the same point 'C' also exists on another frame (Frame I), then it is possible to use this point as a gateway from on frame to another. When point 'C' is common in both Frames I and II, we can 'bisociate' these two templates. Now with the aid of point 'C' the solution may be found in Frame I (as depicted with point 'B') or information from Frame I can be adopted by Frame II. This can also be considered as analogous thinking, because an analogy, through point 'C', is made between two seemingly unrelated templates. Koestler claims that this is how humor works. When someone is telling a joke, the receiver applies all given information on a knowledge template. When the joke teller drops the punch line, the receiver automatically searches this particular template for information related to the punch line. They will not laugh at the joke unless they find a point 'C' on the given template that links it to a completely different template. Once the 'bisociation' has been made between two seemingly unrelated templates, the receiver reacts by laughing at the absurdity.

Both of these approaches to thinking are the roots of creativity. In a strong sense, creativity deals with the generation of new ideas. When working on a problem, new ideas must be somehow generated because the existing ideas are not suitable for solving the problem. All ideas are a function of knowledge. In pursuit of a new idea, someone must either gather knowledge externally (i.e. learn something) or incorporate knowledge from another template, or, most beneficially, employ a combination of both. So why is it so difficult to generate new ideas? Firstly, learning new material may prove to be difficult if a person does not have the adequate knowledge templates to accommodate new information. Secondly, thinking laterally violates the operating nature of the brain. Thirdly, is the presence of what Whetten & Cameron (1990) call 'conceptual blocks'.

Conceptual Blocks

Conceptual blocks are in part the result of the linear nature of the brain. They prevent any bisociative or lateral thinking. They are caused by factors that influence the way a person develops his/her knowledge template. Several of these influences are outlined by Hyman (1998):

- Perceptual: Understanding of the problem is only confined to an existing template.
- Cultural: Socially created templates that make the person behave 'normally'.
- Environmental: Anything within the person's surroundings that distracts the person from thinking any way other than linearly.
- Emotional: Past experiences involving deep feelings can create undesirable knowledge templates.
- Intellectual: Not enough information contained on a template.

These potentially adverse reasons give rise to the conceptual blocks identified by Whetten & Cameron (1990). The following is an overview of the major types of conceptual blocks and their associated characteristics:

- *Constancy*: Vertical thinking and using one language. Instead of attempting to think laterally, the subject is content to search for a solution on one template only. Looking at things one way. Instead of making use of other verbal, symbolic, sensory, emotional and visual languages, the subject employs only one type of language to approach the problem. Communication and translation of languages is a crucial ability in design and will be discussed in the familiarization chapter.

- *Commitment*: Stereotyping situations and the avoidance of analogous thinking. Stereotyping the problems means trying to 'pigeon hole' problems. Committed people avoid abstraction and 'stepping back' to look at the 'larger picture'. This means considering all factors that may influence the problem rather that just treating the symptoms. Commitment means refusing to examine commonalties between the given problem and other situations, and associating the related phenomena.
- *Compression*: Defining the boundaries too narrowly. This refers particularly to two terms that will be introduced latter, namely the 'conceptual spaces' and the 'Klondike spaces'. For creative thinking to occur the 'conceptual space' must be transformed and the 'Klondike space' must be effectively navigated. Basically this means that a compressed thinking individual can't get past his artificial boundaries and can't filter out the useful information needed for solution. More on both these topics later.
- *Complacency*: Not thinking at all and not asking any questions. These 'sad' cases involve individuals that are used to taking orders, don't think for themselves and don't question the situation. During the familiarization approach to design, the designer must ask as many questions as possible to get aquatinted with the environment. The most important question is the question 'why?'. Why are things the way they are? This is one way of shaping the designers understanding of the need. More on familiarization in a later chapter.

Before a discussing further approaches to 'creative thinking' to eliminate these conceptual blocks, it is appropriate to look at the failure of a very popular 'creativity' technique, namely 'brainstorming'.

Brainstorming

Everyone at one time in his or her academic and professional tenures has come across the term 'brainstorming'. The term is so loosely used that it could mean anything from a constructive solution finding meeting for a problem to an unproductive casual bull session. The brainstorming technique is attributed to Alex F. Osborn who initiated the technique in 1938 and developed it fully in the 1953 (Osborn, 1979). The main objectives of this technique were for a group of people to turn off their critical thinking and to generate as many solutions as possible to a given problem. After looking over the results critically, if one or two of the generated ideas are worthy of further investigation, in pursuit of the eventual solution, then the brainstorming session was considered successful.

The actual 'success' of brainstorming is open to interpretation. Arguments range from the accolades and endorsement of Rawlinson (1981) to the criticisms of classical brainstorming by Holt (from Eder, 1996). Based on the experiences of the author and design oriented staff members of the Mechanical Engineering Department at the University of Calgary, classical brainstorming is very weak. It does not effectively provide the students with a method of generating useful solutions to their problems. People find their ideas from other sources. So what can be a possible explanation for the apparent lack of success using brainstorming?

Common social explanations include incompetent leaders, dominating individuals, passive individuals, inability to cooperate, fear of being foolish, and disturbing interruptions (Holt, from Eder 1996). Aside from these behavioral reasons, there appears to be, more importantly, a fallacy in the fundamental theory that forms the brainstorming technique.

Osborn believed that there are two modes of thinking (Osborn, 1979 and Rawlinson, 1981). Osborn's dual model of the dual mode brain is shown in figure 4.

Judgmental	Creative
Logic	Imagination
Unique answers	Many answers
Analyzing	Ideas
Comparing	Visualizing
Convergent	Divergent
Choosing	Anticipating
Vertical	Lateral

Figure 4: Osborn's Modes of Thought

Osborn's dual mode brain is analogous to the dichotomy of the brain as accepted by contemporary psychology. Today this is referred to as left or right brain thinking. The left side is deals with more concrete, tangible, logical and structured information. The left side is falsely but commonly associated with mathematics, sciences and engineering. While the right side is said to processes abstract, intangible, emotional, and unconstrained ideas and notions. The right side is stereotyped with arts and humanistic studies. The following models of the left/right brain dichotomy by Ornstein (1977) and Nezel (1995 from Eder, 1996).

Left Hemisphere	Right Hemisphere
Active	Receptive
Explicit	Tacit
Propositional	Appositional
Lineal	Nonlineal
Sequential	Simultaneous
Focal	Diffuse
Time	Space
Verbal	Spatial
Intellectual	Intuitive

Figure 5: Ornstein's Cerebral Dichotomy

Intellectual	Intuitive
Systematic Methodical Analytical	Volatile Unsteady Non-calculable

Figure 6: Nezel's Modes of Thinking

According to Osborn, the best ideas can be generated if the person shuts down the left part their brain and only allows the imaginative side to work. That way, in theory, the ideas are unconstrained, unrestricted, and uncriticized. The ideas are supposed to flow out uninhibited and spontaneous. The goal is that only a couple of these ideas are going to be eventually useful. Not only does this method produce poor results but also it is often difficult as a group to come up with a 'significant' amount of ideas. As de Bono (1992) says, this is a scattergun approach were many nonsensical, unstructured ideas are thrown around with the hopes that at least one will be useful.

The fundamental weakness in Osborn's theory is that he believes that creative thinking requires the use of one part of the mind with the other part shut down. It appears, by today's reasoning, that Osborn would think that creativity is a right brain activity since the right hemisphere is responsible for the imaginative, abstract and intangible. Osborn would want the logical, analytical, and critical mind to be suppressed during conceptualization or idea generation. Contemporary notions in psychology strongly disagree. Creative thinking requires the entire brain to be used (Williamson, 1982; Nezel, 1995 from Eder, 1996). Nezel claims that creative thinking is the result of tension between the left and right cerebral halves. Searching for a creative solution to a problem requires initial periods of intense conscious concentration and effort. The issue to be resolved will be then consciously and subconsciously oscillated between the intellectual and intuitive sides of the brain. Any abstract notion produced by the right side will be judged and analyzed by the left. The left will determine if the notion has merit while the right will try to build on the original ideas or introduce new notions. In other words ideas can not simply be the result of 'free thought', mental constraints must be added to the situation.

The absence of constraints and criticism during a brainstorming session is the fundamental cause for poor results. Creative thinking requires the constraints to be in place before ideation can begin. So how does generation of creative solutions for problems 'work'? What is the mechanism, or mental platform, for creative activity to take place? Once knowledge templates and mental constraints have been understood, can the theory of conceptual spaces be introduced.

Conceptual Spaces

Creativity requires constraints. Conceptual spaces are 'areas' that are defined by the existing constraints imposed on the system or the given situation. They are mental or physical areas that allow the performer to work within certain parameters while searching answers.

The following is a well known example of the use of conceptual spaces in science. By the end of the 19th century, Russian chemist Mendeleyev began grouping elements according to their known properties and behaviors. Mendeleyev's (from 1905 text) original arrangement of atomic elements is shown in figure 7:

Series	GROUPS OF ELEMENTS								
	0	I	II	III	IV	V	VI	VII	VIII
1	—	Hydrogen H 1·008	—	—	—	—	—	—	
2	Helium He 4·0	Lithium Li 7·03	Beryllium Be 9·1	Boron B 11·0	Carbon C 12·0	Nitrogen N 14·04	Oxygen O 16·00	Fluorine F 19·0	
3	Neon Ne 19·9	Sodium Na 23·05	Magnesium Mg 24·3	Aluminium Al 27·0	Silicon Si 28·4	Phosphorus P 31·0	Sulphur S 32·06	Chlorine Cl 35·45	
4	Argon Ar 38	Potassium K 39·1	Calcium Ca 40·1	Scandium Sc 44·1	Titanium Ti 48·1	Vanadium V 51·4	Chromium Cr 52·1	Manganese Mn 55·0	Iron Cobalt Nickel Fe Co Ni (Cu) 55·9 59 59
5		Copper Cu 63·6	Zinc Zn 65·4	Gallium Ga 70·0	Germanium Ge 72·3	Arsenic As 75	Selenium Se 79	Bromine Br 79·95	
6	Krypton Kr 81·8	Rubidium Rb 85·4	Strontium Sr 87·6	Yttrium Y 89·0	Zirconium Zr 90·6	Niobium Nb 94·0	Molybdenum Mo 96·0	—	Ruthenium Rhodium Palladium Ru Rh Pd (Ag) 101·7 103·0 106·5
7		Silver Ag 107·9	Cadmium Cd 112·4	Indium In 114·0	Tin Sn 119·0	Antimony Sb 120·0	Tellurium Te 127	Iodine I 127	
8	Xenon Xe 128	Caesium Cs 132·9	Barium Ba 137·4	Lanthanum La 139	Cerium Ce 140	—	—	—	— — —
9		—	—	—	—	—	—	—	
10	—	—	—	Ytterbium Yb 173	—	Tantalum Ta 183	Tungsten W 184	—	Osmium Iridium Platinum Os Ir Pt (Au) 191 193 194·9
11		Gold Au 197·2	Mercury Hg 200·0	Thallium Tl 204·1	Lead Pb 206·9	Bismuth Bi 208	—	—	
12	—	—	Radium Rd 224	—	Thorium Th 232	—	Uranium U 239		
	HIGHER SALINE OXIDES								
	R	R_2O	RO	R_2O_3	RO_2	R_2O_5	RO_3	R_2O_7	RO_4
	HIGHER GASEOUS HYDROGEN COMPOUNDS								
					RH_4	RH_3	RH_2	RH	

Figure 7: Mendeleyev's Periodic System of Elements

Mendeleyev's table maps out known information within certain boundaries. These boundaries, or constraints, are based on the known properties of the elements at the time. The way Mendeleyev grouped and classified the atomic elements created spaces on the map. These extra spaces suggested that there is information yet to be added to this general map. This meant new elements are still to be discovered. As advances in physical chemistry progressed into the 20th century, new elements were indeed discovered and placed in their appropriate space. The beauty of Mendeleyev's table is that it allowed information to be discovered and it predicted the properties of that information before it was formally known to science.

The following generalizations can be made of the Periodic Table that apply to most conceptual spaces, whether they exist in the mind of the designer or take a physical form:

- Known information is confined within defined boundaries.
- Information is grouped into patterns and discrete units that can be analyzed.
- Certain gaps exist on the map that permit unknown information to be added.

When someone tries to generate ideas, they do it in response to a certain problem or provocative situation. The foundations of any problem are sets of information in the form of constraints or criteria. In a design problem the constraints come from the existing patterns in the designer's mind and from the constraints as specified in the design problem's definition. Once these constrains are initially established, the designer can explore the spaces within these parameters for a possible solution.

The idea behind the conceptual space approach is to include constraints, criticisms and evaluations while generating solutions. This goes against Osborn's "free thinking" random brainstorming approach. As Boden (1994) states: "To throw away all constraints would be to destroy the capacity for creative thinking. Random processes alone, if they happen to produce anything interesting at all, can result only in first-time curiosities, not radical surprises."

The following is an example, drawn from the thesis project, of how a designer may set up a conceptual space in their mind. Of course this process and resulting conceptual space is intangible, but for explanatory purposes it will be crudely illustrated in the following figures. Also, realistically the constraints and their corresponding conceptual spaces are much more complex and multidimensional than what is about to be presented.

Assume the following goal is to be achieved: "*Find ways to prevent a wheelchair from tipping sideways*." The initial constraint associated with this statement is the visual constraint of the wheelchair. Based purely on experience, the performer already knows how a wheelchair looks like and what it does. So the first boundary of the conceptual space will eliminate anything that has nothing to do with the image of the wheelchair, such as Australian geography, cable cars, the Pygmies of the Congo, peanut butter sandwiches, etc. Another boundary based on the goal statement is related to the performer's understanding of tipping and stability. Again, the boundary will rule out anything that is not related to stability. Further boundaries are a function of extra information being added to the problem. For example if the government that regulates institutional wheelchairs says that no modification of the wheelchair can be done, then the next constraint of the conceptual space would eliminate any thoughts of altering the existing frame of the wheelchair. If the performer learns that this wheelchair problem is related to the institutionalized elderly, then another boundary is created that blocks out knowledge not related to the elderly on one side while keeping all personal knowledge of the elderly on the inside of the conceptual space. Of course many more boundaries could be drawn depending on the amount of information known at the time. Design constraints, criteria and considerations regarding costs, resources, deadlines, manufacturability, etc., could be included as parameters for the conceptual space.

From the above information the following boundaries can be labeled:
Boundary **A**: Wheelchair knowledge.
Boundary **B**: Knowledge of stability.
Boundary **C**: No modification of wheelchair frame.
Boundary **D**: Information about the elderly.

Figure 8 depicts these boundaries creating a mental 'intangible' conceptual space. Boundary lines are labeled at their endpoints.

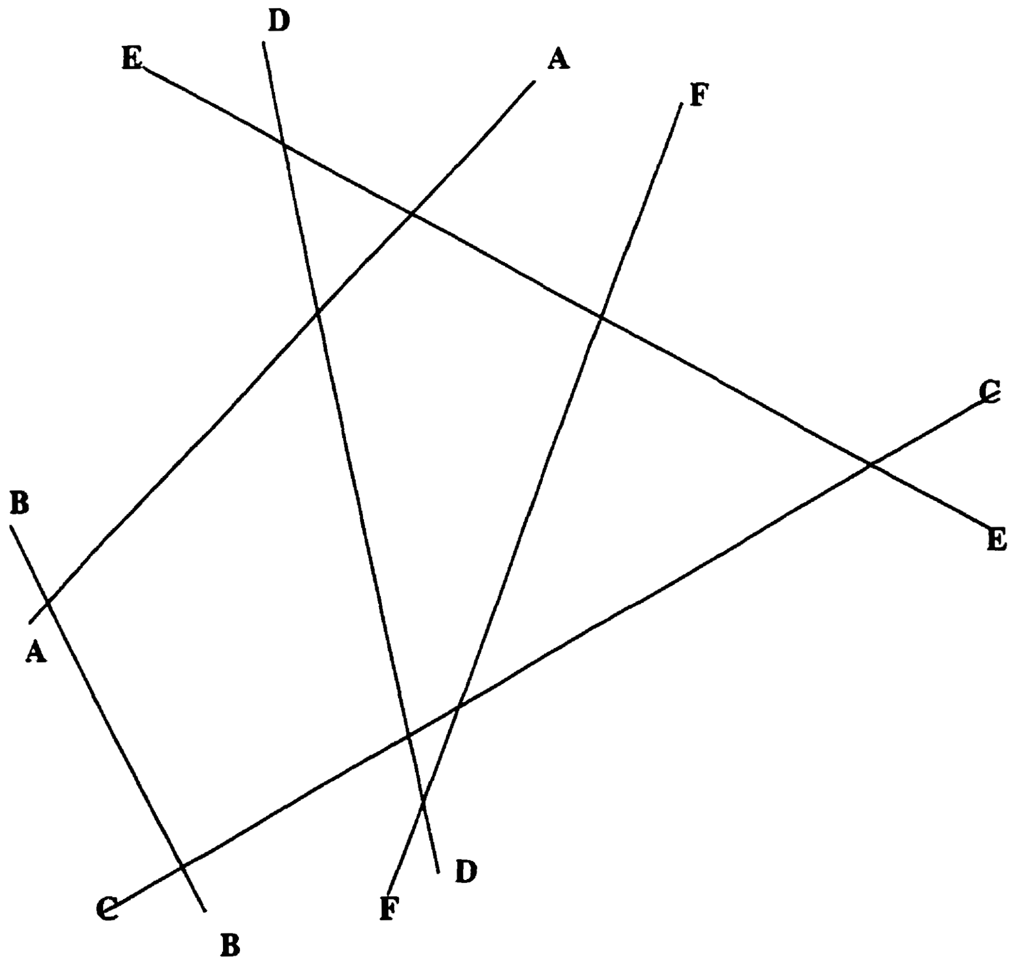

Figure 8: Conceptual Spaces Example

Figure 8 shows the four boundaries of interest (A, B, C, and D), and also other boundaries that exist in the performer's mind. These boundaries (E, F, etc.) could be irrelevant or they could 'open doors' to unforeseen information leading to the solution. As it stands the focus of the performer's attention should be within the quadrangle defined by lines A-B-C-D. Within this quadrangle lies all the information, known and unknown, about wheelchairs, stability, government restriction, and the elderly. If each infinitesimal point in the area ABCD represents a morpheme of information, then the amount of information locked within ABCD is still infinite. However, unlike Osborn's random brainstorming, this is a controlled infinity that confines the pool of possibilities. In fact the 'conceptual spaces' process discussed here is a description of the natural process that people tend to go by when thinking of ideas. People naturally want to gather as much information as possible and work mentally within some set of parameters. Brainstorming philosophically tries to eliminate all boundaries. One of the reasons for brainstorming's limited success is that people can't cope with the absence of boundaries and the lack of structure in their reasoning.

Let us revisit the example. Now that the initial goal has been stated, the initial information gathered, boundaries set and the conceptual space formed, the next instantaneous step is the application of an appropriate knowledge template. The performer's brain immediately scans its library of knowledge template and tries to find the best template or templates that would match the given conceptual space. The template is then placed on the conceptual space (ABCD) as shown in figure 9.

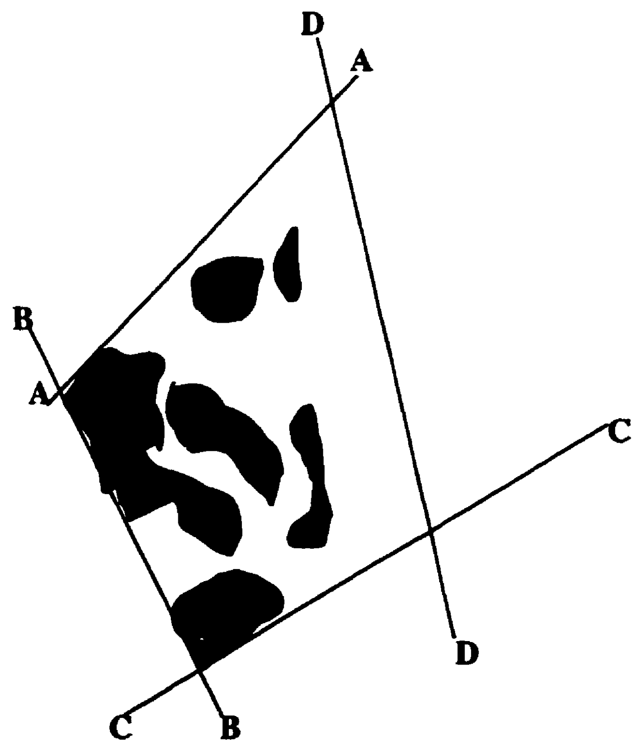

Figure 9: Conceptual Space with the Application of a Knowledge Template

The dark areas within the conceptual space in figure 9 represent the areas of knowledge possessed by the performer about the given problem under the given boundaries. There are a lot of empty spaces on the template. These represent areas of knowledge yet to be discovered, or learned, by the performer. The forms of these dark patches (areas of knowledge) within the conceptual space are unique to the performer and are ultimately a function of the performer's experience. For a professional rehabilitation engineer the above conceptual space ABCD maybe considerably filled, while people that don't deal with wheelchairs or stability will have many more empty spaces in this particular conceptual space.

Understanding the formation of these dark patches, otherwise known as Klondike spaces, is important for finding a solution to the given problem.

Klondike Spaces

Once the performer places their knowledge template on their perceived conceptual space then they can start searching for solutions within the areas of known and unknown knowledge. These regions of information scattered on the knowledge template are called Klondike spaces. Perkins (from Boden, 1994) calls these regions Klondike spaces because searching for solutions within a knowledge template is analogous to searching for gold deposits as in the Klondike gold rush of 1897-98.

While searching for solutions and navigating through their Klondike spaces, performers run into four types of problems that may impede creativity:

Oasis: The Oasis problem is the most common type of problem experienced by professionals or people that know a lot about the subject in question. People try to stick to known 'tried-and-true' solutions to given problems. They do not want to venture beyond the oasis of knowledge fearing failure. Staying in an oasis may produce workable solutions, however these solutions are almost never original. In the example given, oasis solutions for stability of a wheelchair could be lowering the center of gravity of the chair or widening the chair, which are the obvious answers for most engineers.

Isolation: In the Isolation problem, the performer may 'know' of an ingenious solution but does not know how to achieve it. For example in the wheelchair case, an anti-gravity wheelchair would solve the tipping problem but no readily known method has been devised for anti-gravity. Once obstacles have been overcome the isolation problem, revolutionary inventions could arise.

Rarity: The Rarity problem occurs when the performer explores an area unknown to him. He may have to reinvent or rediscover something for himself because that knowledge is not present. Most of the answers that he finds could be irrelevant or fruitless. However this is the area where truly successful ideas can be found.

Plateau: When a performer encounters the Plateau problem, he is in a region of the conceptual space that yields mediocre solutions. The answers are neither bad but at the same time not so good. They will marginally satisfy the problem requirements without any emphasis on originality.

Up until now, all the mental processes described above are perfectly natural for all human beings. Everybody by nature has the tendency of confining a problem within workable boundaries. Likewise everyone will apply the knowledge that they have stored to the problem as they perceive it. They will search all relevant knowledge or get more knowledge through research or empirical activities. They may even try to derive the knowledge by 'reasoning out' the solution logically just like in de Bono's 'tracks'. And by going through all these processes, the performer may derive solutions to the problem. Some solutions may be poor, others may be standard and satisfactory, still others may be viewed as exceptional but very few will exhibit characteristics of true creativity. The reason for this is that creativity is unnatural. In order for the performer to emerge with an eventual creative solution, they would have to perform an unnatural mental act! This unnatural act involves transforming the conceptual space.

Transformation

Once the natural mental foundations for finding a solution of the problem have be laid, the step between going from 'logical' to 'creative' is transformation. When a conceptual space is transformed, new knowledge or information is added to the space. This knowledge is not the type of 'waiting-to-be-discovered' knowledge, such as the gaps in Mendeleyev's periodic table. This new knowledge seemingly is not a part of the existing conceptual space. This is why the present conceptual space and its parameters must be transformed to accommodate the introduction of this new knowledge.

Creative ideas occur under two types of transformations:

Removal of a boundary: If an existing boundary that defines the initial conceptual space is removed or altered, it permits information from other conceptual space to enter. In fact a new conceptual space is created. Looking at figure 8, if boundary D is eliminated, then the new concept space will be defined by lines A, B, C, E and F. In retrospect the removal of a boundary is easier to do than what the performer originally thought. This is because many boundaries are self-imposed and preconceived. They are not crucial for the solution of the problem but many performers, by nature, tend to think they are necessary and therefore are hesitant to touch them.

The following is an example from the author's experience when dealing with the problem of wheelchair lateral stability. Many occupational therapists stated that putting outriggers on the sides of the wheelchair may prevent lateral falls but they will also interfere with doorways and nearby objects. Therefore the self-imposed constraint was that no outriggers could be permitted as a solution because they would impede wheelchair maneuverability. But what if the outriggers were designed in such a way to permit wheelchair passage through doorways and also to prevent lateral tipping. Once the no outrigger barrier was removed, a new was conceptual space created. The new concept space contained outriggers and other mechanisms, such as the quick-return spring-loaded mechanism idea. This 'spring-load' concept was adopted in conjunction with the outriggers to create the solution to be discussed in the mechanical solution section of the report in Appendix B.

Association with another knowledge template: The second type of transformation of the conceptual space is making the connection between the existing conceptual space and another completely different knowledge template. This is just another way of stating de Bono's lateral thinking and Koestler's bisociation as discussed earlier. Once the individual starts searching their conceptual space, they may find a piece of information that is analogous to a piece of information found on another template. They 'leap' onto the other template and gather as much seemingly relevant information before coming back to the concept space. Now the concept space is enriched with information that seemingly had no place there originally. This is how some of the greatest creative ideas come about: By making the association between two or more apparently dissimilar frames of reference. Exactly how the performer manages to accomplish such an unnatural feat is unknown. An average person can't *just* do that at will, although everyone is capable of it. It may take a combination of talent, mental training, experience, an adjusted attitude, 'open-minded' perception, thinking with both sides of the brain, and perseverance.

It is very important to state that the introduction of this new knowledge through transformation, could only take place if natural mental boundaries have been laid in advance. If the boundaries are not there then we are back to the brainstorming scenario where 'off-the-wall' information is readily admitted but there is no existing mental structure to cope with it. Creative thinking only takes place once the individual has put an effort towards solving the problem 'naturally' and 'reasonably'.

Appropriateness of Creativity in Design

Creativity is part of design: the process, the product and the within the performer. Contrary to popular belief, creative thinking is not only applied in one instance of the process, but throughout the entire design activity. However, there are two places in particular that stress the importance of creativity:

Goal Establishment during Familiarization: During the initial approach to a design problem the performer must attempt to understand the user/client environment, identify their needs and formulate a problem statement. The link between the identified need and problem formulation is a 'window of opportunity' for the application of creative thinking. This link is the goal. The need is a 'solution-free' statement describing the unsatisfactory conditions of the user/client. The goal contains the direction the solution will take. Therefore it is up to the performer to choose whether the solution will be pursued using a 'traditionally' path, or maybe something unusual, unexpected, innovative, or radical. The later characteristics are qualities of creative thinking.

Conceptualization during Actualization: The problem statement specifies what the solution should achieve but doesn't specify how to achieve it. Conceptualization is the traditional phase where ideas are generated to find a solution to the problem. This is the time where most of the creative thinking can take place. The performers now know the constraints, they go about forming their conceptual spaces and applying their knowledge templates. Many of the proposed solutions will be known, or standard or expected solutions recalled from their knowledge templates. If there is an attempt to transform the concept space and bringing in unexpected knowledge that appears to be a satisfactory solution, then the conceptualization phase fulfilled its potential for creative thinking.

This sophisticated level thinking will be explored in both phases of design as applied to the thesis project.

Chapter Four
Familiarization

Are engineers only limited to design work within their disciplines? Can engineers solve design problems outside their area of expertise? How can a mechanical engineer understand an entirely different industrial culture or professional environment? Is it possible for engineers to improve upon their existing approaches to design related problems?

Given the current expectations of industry and academic regulators, the movement toward developing holistically oriented engineering designers has begun. Investigating the posed questions are the first steps toward finding an improved approach to engineering design. Such steps are not typically known by proponents of the Grinter philosophy, but are known by other design oriented disciplines. *Familiarization* is a design approach sometimes used by industrial designers and architects.

The familiarization approach allows a designer to enter a new environment and investigate the client's problem. Similarly the engineering designer can adopt and develop this approach when dealing with new clients. The objective is to identify the client's true problem before attempting to solve it.

Introducing the Wheelchair Project

As part of the design work for this thesis I was faced with the task of entering an unfamiliar environment and providing solutions to my client's problems in terms that they could understand. In order to holistically address their problems, the familiarization approach was adopted and integrated into an engineering design experience.

The wheelchair project represented the realization and application of the familiarization approach. In order to present the facets of familiarization, some project background information is needed. A starting point comes in the form of a brief introduction and the initial chronology of events:

Genesis

In December of 1996 WK Dickson, an advisor and benefactor to the Bethany Care Society submitted a proposal to the Mechanical Engineering Department at the University of Calgary. In it, Mr. Dickson identified a problem with wheelchairs as used by the residents of the Bethany Care Center. At that time he felt that the problem with wheelchair accidents was related to the park brake that is an integral component to every manually propelled wheelchair. Specifically, he encouraged the idea of designing and developing a park brake that would automatically engage and release. According to Mr. Dickson such a device would contribute to the Society's primary objective of "Improving the Quality of Life of the Seniors and Disabled Residents of the Bethany Care Center."

Both the Bethany Care Society and the University of Calgary agreed that there is enough merit to warrant a further investigation of the problem. The University of Calgary, University Technologies International and the Bethany Care Society entered into an agreement to investigate the area of the 'passive wheelchair braking system'. The project would be undertaken by a mechanical engineering graduate student as part of his master's thesis in the field of design. The duration of the project was expected to be two years divided into one-year terms. In the first term the investigation of the problem would be carried out and the findings were to be presented to the members of the Bethany Care Society. It would be then the decision of the Bethany Care Society to pursue the project into the second year. The second year of the project would be designated for the design and development of a solution.

Initial Need

The designer's understanding of the situation was that problems resulted when wheelchair occupants were left unattended without the park brake being applied. Due to a slope in riding surface or the influence of an unexpected external force, the chair would roll off and possibly tip over, ejecting the occupant. As a result of these accidents the wheelchair users sustained injuries ranging from bruises to serious facial trauma. The reasons for not applying the park brake include human error on the part of the caregiver, the physical inability of the wheelchair occupant to apply the brake due to arthritis or paralysis, or the forgetfulness of the user due to some form of dementia. In addition it was thought to be beneficial to the caregiver for not having to apply the brake each time the wheelchair came to a stop enabling the caregiver to focus his or her efforts on the needs of the resident rather than the brake.

Initially Desired Solution

It was initially proposed that the solution to these problems was the development of a passive braking device for the wheelchair. The nature of this device would be such that when the motion of the wheelchair comes to a rest, the park brake would automatically engage and immobilize the wheelchair. When mobility of the wheelchair is then again desired, the brake system would have to automatically release itself. The wheelchair should remain immobilized between a range of slopes of riding surface in both indoors and outdoors. Furthermore, this device or system should not alter the normal performance of the wheelchair, nor should the wheelchair be physically altered to accommodate the system. The system would have to be adaptable to a variety of existing wheelchairs. The system must also ensure the safety of the user and caregivers, meaning it would have to be failsafe and foolproof. Also the cost of the design and development would have to be kept to a minimum.

Analysis and Commentary

At that point in time, I was faced with the elements of the beginnings of a 'typical' design situation:

- Client has a 'problem'
- Client has a 'solution' in mind
- Client expects the designer to execute his/her solution
- Client's background is extra-industrial* (in this case)

*By extra-industrial I mean dealing with a project that is traditionally viewed as outside of the designer's industry. From the surface it may seem inappropriate to involve a mechanical engineer in a geriatric facility. This point will be revised during discussions of the multidisciplinary platform and understanding the user environment. The condition of the problem to originate outside the designer's background lies at the heart of the familiarization approach. This means the designer must be able to enter an initially 'unfamiliar' culture to him/her and solve problems related to that particular culture.

The client has a 'problem': This design project began as many others do: a client with a perceived 'problem' approaches a designer. The client's problem is really a combination of needs, goals and requirements. Whether these needs are the true needs remains to be determined at this stage. The most important point to realize is that the client made the effort to contact the designer because his/her situation at that time was undesirable. The client seeks some form of consolation, satisfaction, rectification, resolution or alleviation.

In the case of the wheelchair project, the client knew that senior citizens in wheelchairs were getting injured. Mr. Dickson, believed that the major cause of these accidents was due to park brake failure. He believed that focusing all effort on the park brake would eliminate accidents. Upon a subsequent interview with him, Mr. Dickson expressed that the overall goal of this project is equivalent to the mission statement of the Bethany Care Society: "To improve the quality of life our senior and disabled residents."

The client has a 'solution' and expects the designer to realize it: Since the client thinks that he knows the real problem, the client also thinks that he knows the solution. This is to be expected since he understands the problem only by the way his brain allows him to see it. Naturally when the brain perceives a problem, the brain quickly scans its library of knowledge templates to match the perceived set of parameters associated with the initial problem. From its best template the brain seeks an idea that becomes the solution the client proposes. The client does not have the knowledge or the resources to realize this solution so he hires a designer to complete the task.

The problem as initially identified by Mr. Dickson lies in the functionality of the park brake. According to him if the park brake automatically engaged when the wheelchair came to a stop, accidents caused by the wheelchair rolling off uncontrollably would be prevented. Therefore Mr. Dickson expected me to 'build' a mechanism that would immobilize the wheelchair when motion of the chair ceased. Furthermore were the added stipulations (client requirements) of making the device foolproof and automatic. The mechanism must automatically prevent further motion when the wheelchair comes to a stop yet automatically allow the wheelchair to move when motion is desired.

To the designer the task of creating such a devise sounded very intriguing. Devising a purely mechanical automatically engaging/releasing brake would require creativity to such a degree as to propel it to 'invention status'. But was this the 'invention' that was warranted in this case? Was this really the solution that was needed? And if this wasn't the necessary solution, how would I know if I'd be investigating the right problem? And if I'm not investigating the right problem, then how does one find the real problem? How does one find out the most significant causes that establish the real problem to solve? Finally, to make matters even more complicated, how does one find the causes of problems that are located initially outside the designer's area of expertise?

According to the approach of familiarization, the answers to these questions lie in the discovery and examination of the client/user needs. The needs assessment phase of this project was critical. An extensive and time consuming investigation of client needs had to be carried out to clearly define the problem. These needs had to be properly identified and evaluated. The task at hand is gathering information and processing it. The designer had to identify the sources of information, the type of information required, and the techniques in obtaining it.

Multidisciplinary Platform

The vehicle for simultaneously finding the needs, identification of the true clients/users and for understanding their environments is the multidisciplinary platform. It is the dynamic foundation that brings together individuals of different backgrounds to achieve a common goal. The multidisciplinary dimension of design is one of the four major influences on any design undertaking. It was identified as one of the 4Ms of design in the first chapter that defined the term design. The other three dimensions included manufacturing, management and marketing. But the multidisciplinary platform is really an omnipresent umbrella that incorporates the other 3Ms and much more. It literally 'brings to the table' anyone who will be influenced by (or influencing) the process or product.

In this quest for defining the needs and understanding the environment of the Bethany Care Center, my multidisciplinary platform came in the form of a multidisciplinary network. The platform can either be a team or a network. A multidisciplinary team is composed of members from different professional backgrounds that work together to attain a common objective. Ideally such teams are formed from the very onset of a project so that all concerns, opinions, considerations and influencing factors are laid out from the very start. Such an approach, which is increasingly used in industry, eliminates the 'over-the-wall' method of actualizing a project. 'Over-the-wall' refers to the situation where there is very little communication between departments. Everyone only does the work related to their department, and passes the maturing product on to another department once they are done with it. In the multidisciplinary approach, all departments or team members are aware of what everyone else is doing. This reduces misunderstandings, redundant iterations and unnecessary costs.

In the case of the Bethany Care Center Wheelchair project, there was no predetermined team nor were there any 'departments' to speak of. I was effectively hired to perform a task. No one else had any obligation or funding to conduct this task with me. The designer was given the responsibility to be placed in charge and in control of this project form the very beginning. Therefore establishing a multidisciplinary team was not the course to take. However, as already mentioned, in order to fully understand the culture and appreciate needs of the BCC, a multidisciplinary platform had to be integrated. It came in the form of a network. A network is a system of interconnected individuals or resources that are used to transmit information. Since I was responsible and in control of the entire operation, I placed myself as the nucleus of the entire network.

As my familiarization with the project developed, the network increased. The main concept behind the familiarization network, is to have as many people as possible aware of the designer's task. Positive input can come from the most unlikely sources; that is why a designer should express their interests to anyone within the client's environment. The designer could make their intentions known beyond the client environment. In such cases the designer must use discretion, especially around potential competitors and opportunists.

The multidisciplinary network should ideally include clients, users, and anyone related these clients and users. Members of the network are individuals that are part of a culture, or environment, which is associated with the user. The designer must enter an unfamiliar environment. As the designer's knowledge about the culture increases, so does the designer's network or team. While working on the wheelchair project, my multidisciplinary network evolved as my understanding of the BCC environment progressed. The multidisciplinary network will be presented as part of the discussions on comprehending the environments and identifying the users/clients.

Identification of the Clients and Users

Recognition of the clients and users is crucial in any design problem. designer s must understand who they are working for, and who will use their solutions. Both the clients and the users are part of the multidisciplinary platform. Their requirements and concerns are vital input that can contribute to the success of the project. Ultimately, they will decide the future of the solution. Their perception of the significance of the final product will determine its success or failure. Therefore it is important to incorporate the users and clients into the design process from the very beginning.

A client is a person or group of people that sponsors a designer to do a job for them. Usually, these individuals will approach a designer with a problem or project in mind. This problem may be certifiable or could be falsely perceived by the client. It is the designer's responsibility to verify the actual problem that needs to be solved. Successful designer s are able to find their own clients and convince them of their problems. The worst thing for a designer to do is convince a potential client that there is no problem. The client largely determines the designer's success. They are the sponsors and they are the ones who will make a decision as to whether or not the solution will be implemented.

Users are the individuals that will, as the name suggests, *use* the solution. If the users of the product are the same people that hired the designer to design it, then the user and the client are one and the same. The user also has an impact on the success of the product. If the user is not satisfied with a product, the client's business may suffer. The needs for most design problems are rooted in the user's unsatisfactory condition. For this reason the designer must not only identify the user, but also explore the user's needs.

During the course of the wheelchair project, my understanding of the client and user was redefined several times. The initial client seemed to be Mr. Dickson. He was the first person to approach the University of Calgary Mechanical Engineering Department with an initial problem. Mr. Dickson is a member of the Bethany Care Society board of directors. He is not a full time employee for BCS or the Center, but he is a benefactor and an advisor on general issues. Next, I was introduced to some of the members of the board of directors representing administrative management. They do not work directly with the wheelchair user nor did they have sufficient knowledge of Mr. Dickson's plans. However the board of directors was the source of funding for this project and they made all decisions regarding the continuation of this project. Therefore I made the following recognition:

- *The Client: is the board of directors of the Bethany Care Society (BSC).*

The identification of the user wasn't as clear as it initially seemed. The obvious assumption was that the user is anyone that 'uses' a wheelchair. However several complications arose during the course of the investigation. The first source of misunderstanding stems from the language used by the BCS. To them, all geriatric residents are known as 'clients'. It must be made clear that the word 'client' in this thesis refers to the body of directors for the BCS. The second difficulty was that of the communication problems that existed between the perceived user and the designer (myself). Many of the geriatric residents have some form of dementia. They can not remember details nor do they have a conscious grasp of their needs. It turned out that the voice of the user was best represented by the occupational therapists and care-giving staff. These are the people that deal with the users directly and have a good understanding of the user's needs. The third problem is that of preciseness in defining the user. Can the user be regarded as anybody that has a wheelchair? Since the project evolved from designing an automatic park brake for a wheelchair to an investigation of wheelchair stability issues, does this encompass any user or just the ones with the stability problems? It was decided that the solution to the stability problem would cater to anyone using a manual wheelchair. Therefore, with these three concerns in mind, the definition of the user for this project is as follows:

- *The User: is anyone who uses a manual wheelchair for sitting or ambulating. The* *therapy and care-giving staff at the Bethany Care Center (BCC) speaks on behalf of the user.*

Comprehension of the User Environment and Culture

For a designer to identify the potential users and the other members that would formulate the necessary multidisciplinary platform, one must understand the environment in which they operate. For the designer this environment may be very different from anything seen before. In my case, I have never been exposed to the type of environment that I experienced in the BCC and the rehabilitation-geriatrics industries associated with it.

From the onset of the project I needed to identify the environments that I would be dealing with. Since the familiarization approach is very similar to a detective investigation, I started from the limited information that was initially presented. I knew that I would be dealing with wheelchairs, and an institution for the elderly. From a series of initial meetings and interviews with the instigator, Mr. Dickson, and the management of the BCC I was eventually able to divide the magnitude of this project into elements pertaining to more specific environments. The basis of selection of these environments stems from the issues raised by the various individuals encountered during familiarization. As mentioned before, the knowledge and identification of the environments is a function of the information provided by the multidisciplinary network. The individuals comprising the network are a function of the environments that the designer identifies. Therefore, the multidisciplinary network and their corresponding environments are interrelated. This situation can be compared to a feedback loop function. The following are the environments encompassed by this investigation:

- *The Bethany Care Society Environment*
- *The Bethany Care Center Environment*
- *The Geriatrics Environment*
- *The Occupational Therapy Environment*

- *The Assistive Technology Environment*
- *The Legal Environment*

The Bethany Care Society Environment: The Bethany Care Society (BCS) is the organization that hired me. Although everyone who works or resides at the Bethany Center is considered part of the Society, I associate the BCS with the administrative body of the entire organization. They are the benefactors to my project and the board of directors at the BCS is the decision making body. The board of directors has been identified as my client. I am held accountable to them and at the end of each work term must report my findings to them. Their mission statement expresses the principle philosophy of the BCS: "To improve the quality of life of our seniors and disabled residents." The representatives of the BSC environment in the multidisciplinary network are the members comprising the board:

- The President
- The Senior Director of Innovation
- The Senior Director of Operations
- The Senior Director of Incidents
- Mr. Dickson (project initiator)

The Bethany Care Center Environment: The BCC is the facility that where all the geriatric residents live and where the care-giving staff works. This is the direct environment of the users and the occupational therapists that represent them. To gain a first-hand understanding of this environment, I took an orientation seminar offered for new employees. I took on the role of an employee of the BCC. I familiarized myself with the staff, their duties and responsibilities, and the building where they work. I observed how caregivers tend to the needs of the residents (including wheelchair users). I listened to the caregiver's comments and suggestions. I attended physiotherapy sessions and studied the behaviors and functional capabilities of the users. I discreetly followed residents throughout the day: getting up, bathroom time, eating, and recreational activities. All this to get a better grasp of the conditions at the BCC. I received valuable input from the following members of my multidisciplinary network, representing the BCC:

- Occupational Therapists (Representatives of the users)
- Physiotherapists
- Care-givers
- Nurses
- Secretaries

The Geriatrics Environment: The study of aging and behavioral characteristics was a totally foreign concept to me. However since the BCC is primarily an old age institution, I had to acclimatize myself to the environment of the elderly. This came in the form of not only visiting the BCC but also being in touch with the geriatrics 'industry'. I contacted geriatric societies, long term care homes, and gerontological research institutes. I even went so far as to put myself in the place of a senior citizen at the BCC. This was done in conjunction with the orientation seminars provided by the BCS. I was subjected to apparatuses that restricted my vision, hearing and mobility. In this condition I was treated like a resident, to get some insight into their everyday world. The geriatrics environment was represented by the following sources as part of my multidisciplinary network:

- Caregivers as the BCC
- The American Geriatric Society
- American Association of Homes and Services for the Ageing
- Wayne State Institute of Gerontology
- International Institute on Heath and Aging, University of Bristol, UK

The Occupational Therapy Environment: Since the majority of the input came from the occupational therapy staff, it was necessary to understand occupational therapy. Occupational therapists (OTs) were the primary voice of the user. They have a conscious grasp of the users' necessities, physical conditions, mental status, social needs, and any behavioral attributes. The OTs perform tasks aimed at improving or maintaining a resident's heath and well being. As part of my familiarization with the OT environment, I attended rehabilitation and physiotherapy sessions with the residents and OTs. The OTs had provided input for my investigation such as identification of typical wheelchair problems. As will be later discussed, the OTs provided incentive to refocus my efforts from investigating park brakes to lateral stability of the wheelchair. As part of my understanding of this environment, I began studying epidemiology. Epidemiology is the study of the causes of accidents and diseases. Since familiarization does not just identify and treat apparent symptoms, but seeks their causes (i.e. needs), a study of the epidemiology of wheelchair accidents was warranted. To get an overview of the type and quantity of the accidents that occur and their causes, I consulted sources on local and international levels. Locally, at the BCC I went over the daily incident reports spanning a period of 5 years. On national and international levels, I located literature, searched databases and made contact with researchers in the field. The statistical evidence that I found was used later as part of my research findings that justified a reevaluation of the proposed problem. Namely, the overwhelming majority of wheelchair accidents are tipping/falling in nature rather than due to park brake failure. The occupational therapy environment was represented by the following sources (more in the official report, found in the Appendices):

- ABLEDATA
- Medline
- Occupational Therapists at BCC
- Director of Incident Reports at the BCC
- Dr. Kirby, Dalhousie University Medical Center

The Assistive Technologies Environment: Since I was dealing with wheelchairs, which fall under the assistive technologies umbrella, this environment definitely needed to be explored. Assistive technologies refer to any physical aid to a person with some form of physical disability. Wheelchairs of all types and other mobility basis were also studied. To become personally acquainted with this technology, I procured several wheelchairs. I spent time operating the wheelchair, trying to identify the conditions and functional limitations experienced by a user. I talked to wheelchair vendors and dealers, trying to understand the vast assistive technologies market. I traveled to New Orleans to see the largest medical equipment exposition/tradeshow in North America. This tradeshow gave me the opportunity to speak with manufacturers and become aware of the issues technology tries to address. I consulted references on rehabilitation engineering and wheelchair design, history and uses. I spoke to a local wheelchair designer/user on his unique perspective on wheelchair design issues. I contacted a prominent wheelchair researcher from Nova Scotia, about the problems faced by everyday users. I also searched international patent offices to get an idea of what has been invented and what types of wheelchair problems were addressed by these inventions. I've included a full list of vendors and manufacturers that I contacted in the thesis's References section. Here are my multidisciplinary network sources for the assistive technologies environment:

- Dr. Kirby, Dalhousie University Medical Center
- Rehabilitation Engineering Research Center on Wheeled Mobility
- Canadian Red Cross
- US and Canadian Patent Offices
- Medtrade Trade Show
- Manufactures (Reference)
- Vendors (Reference)
- Mechanical Shop Technician, wheelchair user and designer

The Legal Environment: An unavoidable environment to consider was the legal environment. Several criteria and constraints for this project came directly out this environment. From the occupational therapists I learned that the government of Alberta controls all institutional wheelchairs and other aids. The government stipulates that there can be no drilling or welding done on the frame of any wheelchair. This means that alteration of the existing frame is illegal. Further more the government organization (Alberta Aids to Daily Living) will not endorse any product that has not met the standards and test of the Rehabilitation Engineers Society of North America and the International Standards Organization. Familiarization with the standards and policies of these organizations was crucial before any conceptualization was to be done. Furthermore, it would have to be established who will have responsibility for the solution, i.e. who is held legally accountable in the event of a failure of my solution in the future? An agreement was reached by the lawyers of the BCS and University Technologies International (which works as a legal liaison for the university and external industries), that the Bethany Care Society will have intellectual property rights to my solution and will be held liable for any accidents. The key nodes representing the legal environment in my network include:

- Alberta Aids to Daily Living – Equipment Manager
- Rehabilitation Engineers Society of North America
- International Standards Organization
- University Technologies International
- University of Calgary Research Services
- Bethany Care Society Legal Advisors

Translation of Multidisciplinary Languages

Once environments have been recognized, it is apparent that individuals associated with these environments have their own languages. These languages are usually verbal, but could be textual, graphic or symbolic. One of the greatest challenges for designer is to translate the languages and viewpoints of the members of the multidisciplinary platform into a language the designer can use. An engineering designer must translate the client/user requirements in to the engineering principles used to create a solution. If for example, a client requires something 'to be strong', the engineer translates the client's concept of 'strength' into ultimate stresses, strains, Young's modulus, material selection, force analyses, etc.

Along the way the designer will experience communication problems. There are three place where communication can fail or be misunderstood: From the transmitter, through the medium and by the receiver. The transmitter may be at fault because they failed to express clearly what was on their minds. The medium may be at fault because the message may be taken out of context. The receiver is usually at fault because they do not have the adequate knowledge templates developed that can accommodate the incoming information. As part of the familiarization approach the designer must develop new knowledge templates that are compatible with the environment of the user or the other multidisciplinary team members. Furthermore, the designer must create a mental link between the new templates and their own existing templates that are part of the designer's environment and industry.

The wheelchair project was no exception when it came to understanding different languages. Each of the environments introduced me to either new words or a different interpretation of words that I already new. For example, the word 'client' in the BCS doesn't refer to project benefactor as is it does in design terminology but to the resident of the BCS. In another example, the word 'multidisciplinary' in BCS terms does not mean people of different backgrounds working toward a common goal, as it does with my terminology. BCS calls this 'interdisciplinary'. For the BCS the word 'multidisciplinary' means an organization that contains different departments, not necessarily working towards a common goal.

A demonstration of my understanding of the new terminology associated with the environments is presented in the Appendix B. The report of findings, which I presented to the BCS, is the product of my research. In order to conduct 'research' one must already have a grasp of the vocabulary and language used in these environments. A broader discussion of the role of research in design and in my project will be presented in the Research section of the Actualization chapter.

When dealing with user/client languages, the designer must pick out their requirements and translate them in to criteria. A requirement is a demand or condition set by the designer, user, client, environment and/or other external influences. A criterion is a quantitative characteristic of design that is to be reflected in the solution. A criterion is a 'processed' requirement.

Some of the requirements were expressed by the occupational therapists. The OTs represented the users. Their greatest concern was that whatever 'device' is invented must work. It must be a 'help' rather than a 'hindrance'. It must be easy to use and must not interfere with the daily activities of the users and their environment. Such concerns translate into the criteria of functionality, compatibility, maintainability, safety and learnability. Other criteria came from sources external to the BCC, representing the occupational therapy, assistive technologies and legality environments. The Wheelchair Design and Selection Issues chapter of the Wheelchair Stability Assessment Report found in Appendix B presents all the criteria to be considered when dealing with wheelchair design. Criteria will also be discussed in the Definition of Problem section of the Actualization chapter.

One of the most significant steps in translation occurred between the languages of the occupational therapy environments and that of engineering. OTs and epidemiological studies claim that the percentage of wheelchair accidents that occurred are tipping/falling in nature. 'Tipping and falling' in mechanical engineering terms are issues of 'stability'. Stability is the property that maintains a body in a desired condition even when the body is subject to external forces. Stability takes into account the relationship of the location of the center of gravity of the object with respect to the object's base.

From the concerns of the OTs it was understood that the wheelchair users are experiencing problems with 'instability'. This meant that the centers of gravity (COG) of the wheelchair-user systems were susceptible to moving beyond the boundaries of the base. Once this happens, a fall occurs. Therefore I devoted a significant amount of research time to stability issues. I explored ways of preventing tipping not only by mechanical methods but also by methods that eliminate the causes of tipping. All findings of my research are found in the Stability section of my report to the BCS, located in the Appendix B.

Abstraction

Abstraction means 'stepping back' and viewing the 'larger picture'. Rather than just honing in on a given task, abstraction takes into account the entire environment or system of environments related to the assumed task. This is done, especially during familiarization and specifically at the beginning, for the purpose of establishing a need. As a design project matures, most activities will be narrowing in on specific details on the solution. This is known as concretization and is directly opposite to abstraction. A common mistake, that I tried to avoid, when starting a project was to start concretizing immediately. A significant amount of time and effort must be placed on abstraction. If properly done, abstraction will not only yield the true needs and set a direction for a solution, but will also help the designer to understand the environments that are involved and the issues they raise.

The primary tactic during abstraction is to ask the question 'why'. The questions what, who, where, when, how, etc. may follow up to any answer, but the primary driving question is 'why'. Why are things the way they are? Why should something be investigated? Why should this situation be improved? Why is there a problem in the first place? Asking the question 'why' repeatedly can take a designer towards theology and philosophy. More to the point, a more practical and graspable unsatisfactory situation may emerge. This is, in effect, the ultimate purpose of asking 'why': to establish the need. Along the way, the designers will familiarize themselves with the environments that contain the unsatisfactory conditions. As the designer's understanding of the environment and conditions increases, so will the multidisciplinary network that provides information.

From the onset of my investigation, I began asking the question 'why'. This led to a series of auxiliary questions. The following are common questions and answers I asked and received from a multidisciplinary pool of sources:

Q. Why was there a request for an automatic park brake?

A. Users were getting into accidents.

Q. Why were users getting into accidents?

A. Possible park brake malfunction.

Q. What happens during these brake related accidents?

A. User rolls away with the wheelchair.

Q. Why do park brakes malfunction?

A. Well, usually they don't fail.

Q. Are such brake related accidents common?

A. Not really.

Q. Is an automatic park brake desired?

A. More or less. It's a novel idea but it must work for it to be effective.

Q. Are wheelchair accidents common?

A. Yes!

Q. Why do wheelchair accidents occur?

A. The wheelchair tips or the user slides out.

Q. When do accidents typically occur?

A. During transfers and when the user reaches out for an object.

Q. What types of wheelchair accidents are most common at the BCC?

A. When user reaches to the side and tips wheelchair sideways.

Q. Has anything been done about sideways tipping?

A. No, nothing yet.

Q. Does the issue of sideways tipping need to be addressed?

A. Absolutely!

The preceding was an example of how abstraction is used to induce a need from a set of environments. The above questions were posed to representatives of all the identified environments. The intention of the example was not to create a linear induction scheme. This was a compilation of questions and answers done over a significant period of time under various circumstances. The point of this example was to show that questions generate answers that in turn generate more questions. Usually this process creates a web of questions and answers.

From this point on, the designer's experience in information management starts playing a role. The designer must know what to do with the information collected. How can the network of questions-answers and the multidisciplinary network be utilized to provide insight given project? The designer can only do this by matching the existing personal knowledge templates with the information as is comes. Effective use of these knowledge templates is a function of the designer's experience. However, in the case of the wheelchair project, adequate knowledge templates were not in place. I had to develop these templates by learning through familiarization and abstracting. Only when these new templates started to crystallize was I able to cope with the information presented.

Abstraction is not a form of research. In *research*, questions are known and knowledge templates are in place. When *researching*, answers to well-defined problems or questions are found. Usually the designer knows where to look for an answer and how to get it. The designer already has a knowledge template established mentally that will cope with the answers found. During research the designer is completing the gaps in an existing template with newly acquired information. In abstraction however, the questions are not formulated and the designer's knowledge templates are not adequate. The designer has no idea of what to ask. Therefore the designer can only start by asking the question 'why'.

Redefined Needs

Familiarization looks at the causes rather than just treating the symptoms of a perceived problem. That means the client/user's true needs, or unsatisfactory conditions, must be identified. Abstraction is a powerful tool used to induce the needs of a design project. Based on these needs a proper set of problem statements can be defined. designer s then have the satisfaction of knowing that they are pursuing a solution to the actual problem and not just treating a 'symptom'.

The investigation commenced May 1997. The primary objective of the designer was familiarization with wheelchairs, the BCC and geriatric accidents. Upon interviewing professionals in these fields at the BCC, conducting literature searches, direct observation and contacting external organizations, it became evident that the needs of wheelchair users have to be redefined. It was discovered that:

- The automatic park brake was not particularly desirable.
- Most wheelchair related accidents were due to tipping and falling.
- There was no known solution to address the case of lateral tipping.

These three points have one thing in common: the issue of wheelchair stability. A user's need stems from an unsatisfactory condition in the user's life. Therefore the unsatisfactory condition observed was that:

- *The Need: Users are very likely to experience an accident due to wheelchair* *instability.*

In all design activity, the designer must conduct some form of need assessment. The events that transpired in my project are typical to many other design situations. The client believes there is a problem and asks the designer for a solution. Many times the problem is not quite accurate, and the client already has a solution in mind for the designer to make. If the designers were to 'blindly' do what the client told them to do, their actions could not be considered to be 'design'. The designers would then be 'builders' or 'craftsmen' rather than 'designers'.

As was seen in my project, initial needs and true needs may vary significantly. What seemed like an unsatisfactory condition with park brakes became an unsatisfactory condition with wheelchair instability. What was thought to be a project of 'building' an automatic park brake became a project of 'designing' methods of preventing wheelchair instability accidents.

By the time a designer has confidently established the client/user's needs, a tremendous amount of information has been collected. The designer has developed new knowledge templates, formed a multidisciplinary platform, identified the clients and users, comprehends their environments, and understands their languages. Now the designer is prepared to formulate a problem that will set the direction for finding a solution.

Goal Establishment: The First Window of Creativity

Based on abstract thinking, the true unsatisfactory condition of the user and client was determined. Even though the new need statement has more useful potential than the original, it is still in a state of vagueness. This vagueness is produced by the level of abstraction that the designer decided to take the situation. This means, how far the designer decided to 'step back'. The further the 'step back', the broader the statement of needs, the more potential for possible solutions.

Now the abstract needs must be pulled into the physical, pragmatic world. A set of problem statements must be developed in order to define the tasks of the designer. A goal is a general statement that responds to the given need. More importantly, the goal sets a direction for solution actualization. A critical step must be taken to define this goal.

The purpose of the first window of creativity is to transform an aimless statement of needs into a directional goal statement. The goal statement is still solution-neutral. Solution-neutral means that that no specific solution is either implied or expressed by the statement of goals. The goal is solution-neutral but sets direction for the designer to pursue.

Creativity is the link that connects needs with goals. This is the first phase where the designer has the opportunity to apply creative thinking. The employment of creative thinking narrows the vagueness of the need into a goal that orients the designer toward a possible set of solutions.

The first window of creativity is more difficult to understand than the second one. The second window of creativity is traditionally called conceptualization. In conceptualization, creativity is applied to change the state of the project from a solution-neutral state to a solution-bias state. In other words, conceptualization is a stage where ideas are generated that lead to a concretized solution. This is not the case in the first window of creativity. In the first window the state of affairs starts as a solution-neutral state and becomes transformed into another solution-neutral state after the application of creativity!

It must be made clear that design does not happen without creativity. As has been discussed in the Creativity chapter, creativity is a viable, credible and compulsory phenomenon that exists in all design activity. Creativity does not occur as a result of guessing or serendipity. It is the result of three important sets of conditions that must be simultaneously in place:

- *Tension*
- *Knowledge*
- *Constraints*

Tension: This refers to the mental tension between the intellectual and intuitive minds. When the designer thinks, the train of thought oscillates constantly between the left and right sides of the brain. Both sides have sets of knowledge temples. In creative, or holistic, thinking the brain tries to make a connection between an analytical knowledge template and an imaginative one. If a successful connection between cerebral lobes is made, an idea is formed. This is an exasperating process because every time the designer 'thinks' a link has been made between the two minds, there always seems to be a piece of analytical information that eliminates the connection. Finally, when a connection is made, there is a release of tension that sparks an idea.

Knowledge: The information that must be present for creativity to occur comes in the form of knowledge templates. Knowledge templates must exist in the designer's mind in order for an idea to be generated. The templates may be old, well-established templates based on years of the designer's experience, or they may be fresh, newly developed templates typical of post-familiarization. In order for a 'creative' idea to be generated, there must be an interaction, an exchange of information, between two or more unrelated templates. Ideas may be generated on a single template, but those will not be considered 'creative' in nature. Creative ideas are only the result of at least two seemingly 'contradictory' or 'mutually exclusive' knowledge templates.

Constraints: Creativity cannot happen without constraints. Constraints are the mental parameters used to construct a conceptual space. A conceptual space can be viewed as a knowledge template that contains all the information known and to be known about the project. Within the conceptual space all idea searching takes place. In order for an idea to be the result of creative thinking rather than regular thinking, the conceptual space must be transformed. Transformation is done either by the addition of information from another template, or by removing a constraint to create a new space that includes new information.

A conceptual space cannot be formed in the absence of constraints. Constraints are composed of all the requirements set from the multidisciplinary platform. Most constraints are external to the designer, they arise from the client/user environments. There are however constraints internal to the designer. These may be perceived obstacles or psychological barriers intrinsic to the designer. Even though these barriers (constraints) may be transformed in the future, they must be initially in place for the designer to start 'thinking', i.e. searching for an idea.

Now that the three sets of factors are in place, the designer has to find a goal for the problem from the redefined needs. To illustrate how a need must be creatively linked with a goal, two examples will be considered. One example will be on a general level, the other will be specific to my project.

A General Example:

Assume a user is a paraplegic individual. The user's unsatisfactory condition (need): *I can't use my legs.*

The need statement is this case does not imply any solution. It does not imply a wheelchair; not even a mobility base. The need statement is solution-neutral, as it ought to be.

The constraints associated with this unsatisfactory condition come from the user's requirements. These may include ***wanting to be functional within user's society***; ***wanting to move around easily***; ***wanting to be independent.*** These three constraints now form the parameters of the conceptual space with the designer's mind. The space is limited but each space has an unlimited amount of infinitesimal points.

The designer applies a knowledge template compatible with the conceptual space. This knowledge template contains all of the information the designer knows about *paraplegics, the inability to use legs, functioning within the user society, social views of paraplegics, mobility, forms of transportation*, etc. The knowledge template, or system of templates, is a function of the designer's experience. The knowledge, now transposed onto the conceptual space, is never enough to completely fill the space.

The designer now searches the knowledge laden conceptual space. The designer may get an idea from areas that contain plenty of information. Such information includes *wheelchairs, mobility bases, strollers, carts, chairs with caster wheels, etc.* The designer may venture into the unknown and fill the information gaps in the conceptual space by doing research. For example: *studying medicine, severed nerves, paraplegia, rehabilitation engineering, physiotherapy, etc.* Ideas may be drawn from the newly acquired information.

Ideas found from 'resident' knowledge and new knowledge do not represent creative ideas. A resident knowledge idea, for example, would be to pursue the solution *mechanically*. A new knowledge goal would be to pursue the solution *by medical means*. Certainly these goals, picked directly from the conceptual space, may become very successful solutions, but they are still not creative. They are not creative because they have emerged by natural means. A creative idea can only emerge if the conceptual space is transformed. A transformation of the conceptual space is unnatural, therefore creative!

A transformation of the conceptual space involves the addition of unrelated information. Removing a constraint or matching information from the conceptual space with a completely different knowledge template can do this. An example of a creative notion would be connecting the *paraplegic's social functionality with an environmental reform* *template*. Instead of changing the paraplegic's condition to match the environment, the environment would be changed to match the paraplegic. This would mean creating a society were everyone can function effectively yet without the use of legs!

Creativity can be used in this way to convert the need, *I can't use my legs*, to the goal, *to design a legless society*. Both the need and the goal are solution-neutral as they must be. No one knows how a society without leg use might look or how to achieve it. The purpose of the goal is only to set the direction for pursuing a solution. As was seen in this example, pursuing the solution *mechanically* or *medically* are good but 'normal', or 'expected', goals. But pursuing the solution ideologically are radical, unnatural, unexpected goals: creative goals.

Establishing the Goal of the Wheelchair Project:

The user is the wheelchair resident of the BCC. Their unsatisfactory condition (need) is that: *users are experiencing wheelchair instability.*

From the abundance of information gathered during familiarization, it is known that the macroscopic goal of the BCS: *To improve the quality of life of the seniors and disabled residents of the BCC.*

This client goal must definitely be considered but is still too vague to establish a useable direction for solution actualization. More information in the form of constraints was needed to set up the conceptual space.

Based on the requirements generated by the multidisciplinary network, the following constraints are known: *There is to be no drilling, cutting or welding the wheelchair frame* (from AADL); *no interference with the surroundings* (OT); *a minimum 200 pound force must be supported* (RESNA).

All the above constraints try to force the designer to create a mechanical solution. In fact every one of the environments involved encouraged and expected a mechanical solution. No mention was made of any other approach. Therefore the 'normal' course to take would be mechanical in nature. This in itself is a constraint in the form of an 'environmental' barrier.

Given the constraints, that form the conceptual space, the knowledge template must be placed. This knowledge template contains the cumulative knowledge of everything that I know and learned about the project thus far. It is the superimposition of all my knowledge templates pertaining to this project. In terms of my understanding of the situation, I know falls occur in all directions: forward, backward and side. Although there are provisional solutions to anterior and posterior wheelchair instability, there aren't any solutions to the lateral tipping case. Therefore I decided to focus my project on the situation of lateral tipping.

Addressing lateral tipping problems could be viewed as a goal. Is it a goal derived by creative intervention? No, because additional factors needed to be realized. Rationally, I was prepared to pursue the goal *mechanically*. All information contained within the conceptual space directed me to invent a mechanism or device.

The creativity was demonstrated when I removed the self-imposed 'mechanical' constraints. I opened the door to other possibilities that are not self-evident. Not only could I address lateral tipping mechanically but also by policy, or education, or environmentally, etc. Therefore the goal that I developed was:

- *The Goal: To prevent lateral tipping in wheelchairs.*

This goal satisfies the conditions of solution-neutrality and creativity. It does not imply any specific solution but it does set a course for solution searching and actualization. It does not imply a mechanical course for finding a solution either. The mechanical constraints were eliminated, allowing non-mechanical methods to be used.

Although the creativity in this example may seem subtle, the point is that this is the opportunity for a designer to pursue a direction not expected of him to do. It was expected of me to do something mechanical. But both a mechanical and non-mechanical solutions were proposed in the end.

Conclusions

An engineering designer can use the familiarization approach as a tool. The engineer develops an understanding of a different client environment from which he is asked to provide a solution. By linking the development of knowledge templates with creative thinking, the engineering designer now has a direction to pursue the solution.

The material and background of this project went beyond the boundaries of mechanical engineering knowledge. Design and administrative techniques borrowed from the fields of industrial design, therapy, management, etc. were employed to develop a familiarization approach tailored to mechanical engineering design. By applying familiarization as shown to the wheelchair project, an engineering designer can understand how to deal with design problems that go beyond the engineering knowledge base.

Chapter Five
Actualization

This chapter deals with the early stages of actualization; those that are most directly influenced by familiarization. Emphasis is placed on the application of creativity during conceptualization.

All traditional stages of design occur during actualization: problem formulation, conceptualization, embodiment, detailing, production, and implementation. While familiarization is primarily a solution-neutral set of activities, actualization is solution-focused. All actions are aimed at concretizing the solution.

The actualization section of this thesis will not be developed to the extent of the familiarization section. Actualization is based on the foundations set by the familiarization approach. Actualization is interested in the results of researching, solution generation and production. The full extent of the results is provided in the Appendices in the form of the reports presented to the BCS.

Even though the roles of familiarization and actualization differ, one phenomenon is common in both phases: creativity. The primary role of actualization is to bring a solution to existence. Therefore creativity must be exercised throughout the phase of actualization. Creativity is not just a technique used for idea generation. It must satisfy the condition of 'act of creation' as well as 'application of an original method'. Through creation something is brought into existence.

Definition of the Problem

One of the most fundamental, yet often overlooked, stages in actualization is the definition of the problem. A 'problem' is a set of statements that tell the designer what must be done in response to the needs. The problem only tells what the solution must do. It does not tell the designer what the solution is or how to achieve the solution.

The problem definition is the outcome of the knowledge obtained from familiarization and the application of creativity. The problem definition begins where familiarization ends. If familiarization is ignored, the designer not only wastes time and money solving the wrong problem but also provides the wrong 'solution' to the client and user. It is not enough to treat an apparent symptom, but to respond to the symptom's causes.

The set of statements composing the problem can be divided into three components. For the sake of clarity, the problem is decomposed into the goals, objectives, and constraints. Each problem constituent plays a role in problem definition and design actualization.

Goals

The goal is a response to the need that sets the direction of the design process. If familiarization was used as the initial phase of the project, then the goal would be a solution-neutral statement that would set the course for solution actualization.

The goals chosen for this project were macroscopic as well as microscopic in nature:

- *To improve the quality of life of the seniors and disabled residents of the BCC.*
- *To prevent lateral tipping in wheelchairs.*

The macroscopic goal indicates that all actions should be aimed at improving the quality of life of the BCC residents. Of course this statement is quite broad but the general intention of the action is understood. The macroscopic goal was determined by the knowledge gained during familiarization.

The microscopic goal was generated by the application of creativity during the later stages of familiarization. It focuses in on area of lateral tipping prevention but it doesn't specify that only a mechanical solution is needed.

Objectives

The objective is a detailed set of statements that describe the primary function of the design. This function is influenced by a set of criteria that both the designers and clients selected to be most important. The objective is otherwise known as the performance specification.

At this point I had to specify a 'mechanical' pursuit formally. All non-mechanical pursuits had to be done informally or unofficially. The formulated objective was:

- *To design a mechanism that will prevent tipping of the wheelchair in the lateral direction. The mechanism must be stable, attachable and safe.*
- *To propose a non-mechanical method of tipping prevention.*

Constraints

The constraints are imposed design attributes that must be satisfied by the solution. The designer can not change them. If the final design does not reflect that the constraints are satisfied, then the design is a failure. All constraints were discovered during familiarization and most constraints were aimed at a mechanical solution.

All constraints emerged from the different environments that were identified during familiarization. The constraints are:

- *No drilling, cutting or welding onto the wheelchair (AADL regulation).*
- *Device must not interfere with surroundings (OT requirement).*
- *Must support a minimum 200 pound force (RESNA test requirement).*

The Revised Problem

Upon approval of the Bethany Care Society (the client) the investigation refocused from making a park brake to addressing the needs and problems associated with wheelchair instability. A serious effort was made to find information on the problems of lateral stability and sideways tipping problems. Based on this information the new problem statement was: "To find possible solutions to lateral wheelchair stability in a geriatric setting." The entire problem exploration was subject to the goals of the Bethany Care Society, the needs of the users, the constraints imposed by AADL, the criteria set by various professionals and considerations of the user/caregiver environments.

Considerations

A consideration is any object or condition that is accounted for by the design. Considerations are primarily composed of constraints and criteria.

Criteria are quantifiable subjective attributes that are to be reflected by the design. These attributes have been identified through the problem familiarization and research phases of the process. During these phases the client requirements were recognized and translated into feasible design requirements and considerations.

Criteria have been collected from the following sources: users, nurses, occupational therapists, physiotherapists, doctors, manufacturers, vendors, designers, rehabilitation engineers, disability/geriatric researchers and mangers. It must also be noted that these criteria are interdependent and must be approached holistically. The resulting criteria (considerations) that are to be included in the design are:

- *Safety*: Must be safe to user and caregiver.
- *Functionality*: Must work and be effective.
- *Compatibility*: Must fit onto existing wheelchair and not interfere with surroundings.
- *Strength*: Must be strong enough to support user.
- *Manufacturability*: Must be easily built.
- *Affordability*: Must be inexpensive to make, buy and use.
- *Maintainability*: Must require little and easy maintenance.
- *Dependability*: Must work over long periods of time.
- *Learnability*: Must be easy to use.
- *Flexibility*: Must be adaptable to variety of wheelchairs.
- *Assembleability*: Must be easily assembled together and fixed to the wheelchair.
- *Acceptability*: Must be accepted by users, caregivers and administration.

Research

Research evolves out of familiarization. Familiarization generates newly posed questions. Familiarization develops the necessary knowledge templates that the designer will use to understand the problem and start solving the problem. Naturally, these templates are incomplete. There is plenty of information that needs to be added. However, the designer now has an existing mental structure that indicates what information is needed and where to look for it. This structure also accommodates new information. Familiarization creates the foundations for the research.

Research can only be properly conducted when the adequate knowledge templates are in place. This is similar to adding new atomic elements onto the periodic table since there are allocated spaces for this new information, i.e. the new elements. In the same way my knowledge templates of the environments required more information.

All research material is presented in Appendix B. The following is a synopsis of the findings of the major areas of research investigated as related to the problem:

Wheelchair Issues

Any designer working on a wheelchair related design project must be aware of all wheelchair issues. The assistive technologies and occupational therapy environments raised most of these issues, include:

- classification of wheelchair users;
- classification of wheelchairs;
- wheelchair user needs;
- assistive technology prescription considerations;
- wheelchair components and their functionality;
- industry standards and regulations;
- assistive technology design criteria.

Epidemiology

Epidemiology is the science that deals with the cause and prevention of diseases and injuries. Since the entire project is done in response to wheelchair accidents, understanding all issues involved in accidents is crucial. The word epidemiology stems from the geriatric and occupational therapy environments. Issues to consider include:

- General geriatric accidents related to postural stability, light, health, location, reaction time, time and date, drug, and mental status.
- Wheelchair accidents: frequency in years, age distribution, fatalities, location, body

parts injured, and the natures of both fatal and nonfatal accidents.

Stability

Stability is the root of the problem. All issues involving tipping/falling, brought up by the occupational therapy environment, are understood by engineers as stability. Stability is part of the engineering vocabulary. It can be analyzed and clearly understood by the engineering designer. The stability issues are:

- Stability of the individual: geriatric stability, sway, postural stability, ergonomics, and functional stability.
- Stability of the chair and person-chair system: structural stability of the chair, static (anterior, posterior, lateral), dynamic (anterior, posterior, lateral, directions).

Management

Since the client is the board of directors of the BCS, issues had to be addressed on that level as well. The effectiveness of care home management will have an impact on the resident-user. Therefore the client (and designer) must be aware of all management and administrative items:

- Awareness of user needs
- Care home administration
- User environment
- The multidisciplinary team
- Staffing considerations
- Education and preventive measures

Conceptualization: The Second Window of Creativity

In actualization, the designer has a second opportunity to apply creative thinking. The purpose of creativity in familiarization is to set a direction for finding a solution, the purpose of creativity in actualization is to find the solution. It is the transformation from a solution-neutral state to a solution-bias state. In actualization, this window of creativity is traditionally called conceptualization. The designer tries to generate a concept that can be developed into a solution.

Through familiarization, the designer has acquired knowledge of the environments and the necessary constraints for conceptual space formulation. Once constraints are in place, the descriptive creative process is as follows:

- Formulation of conceptual space with the constraints as the parameters (figure 10).
- Application of relevant knowledge templates onto the conceptual space (figure 11).
- Transformation of conceptual space: through a link with an another mutually exclusive template or by removal of a perceived constraint (figures 12a and 12b).

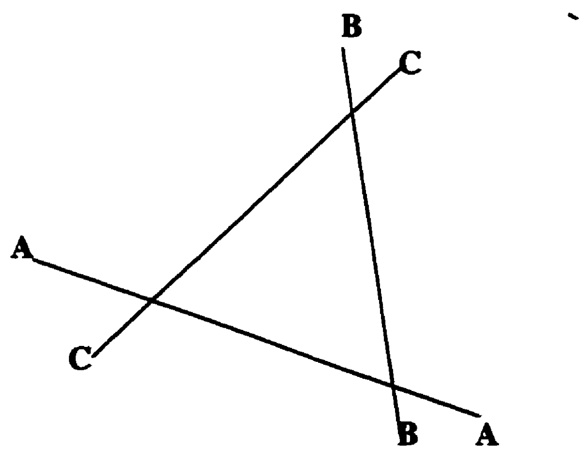

Figure 10: Conceptual Space formed by Constraints

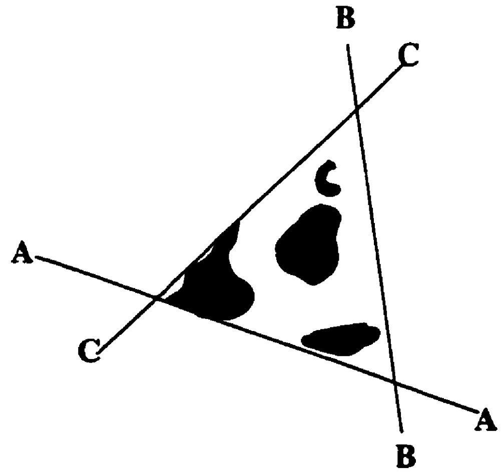

Figure 11: Conceptual Space after Application of Knowledge Templates

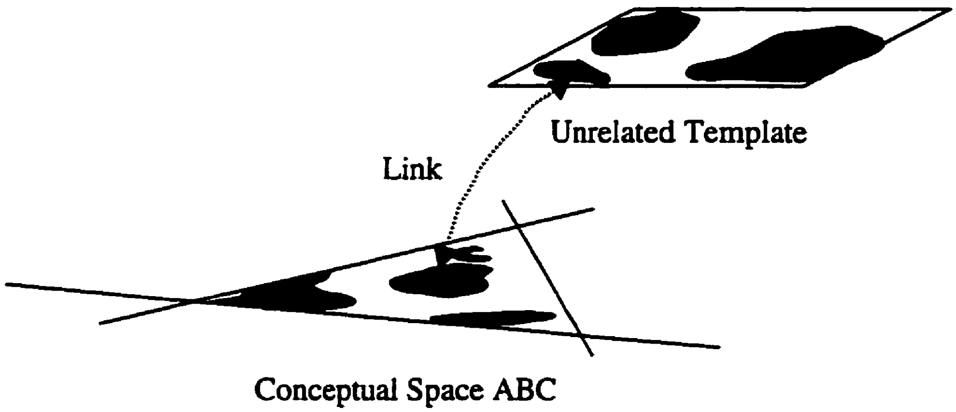

Figure 12a: Transformation by Template Linking

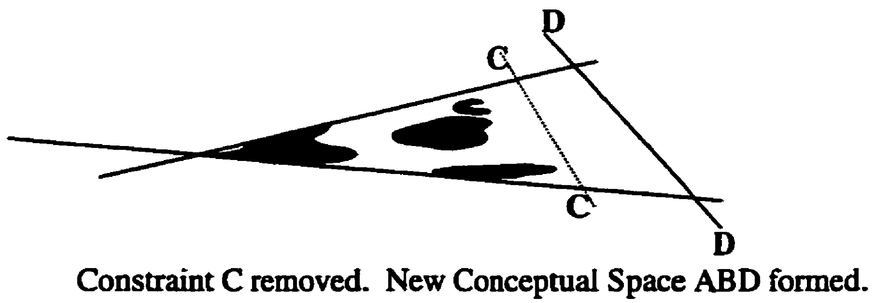

Figure 12b: Transformation by Removing Constraint

The stages of creative thinking described above are not a procedure. There is no prescriptive method or technique to generate a creative outcome each time. The only significance Figures 10-12 have is that they generalize the events that must happen in the designer's mind during creative thinking. Creative thinking is a result of existing constraints, mental effort and prior knowledge.

The Mechanical Solution

To achieve a mechanical solution 'to prevent lateral tipping in wheelchairs', we begin with a set of conceptualization constraints. It is the designer's decision which design criteria will be used as conceptual constraints.

The conceptual constraints chosen were:

- *No drilling, cutting or welding onto the wheelchair (AADL regulation).*
- *Devise must not interfere with surroundings (OT requirement).*
- *Devise must support a minimum 200 pound force (RESNA test requirement).*
- *Safety: Must be safe to user and caregiver.*
- *Functionality: Must work and be effective.*
- *Compatibility: Must fit onto existing wheelchair and not interfere with surroundings.*
- *Strength: Must be strong enough to support user.*
- *Manufacturability: Must be easily built.*
- *Flexibility: Must be adaptable to variety of wheelchairs.*
- *Assembleability: Must be easily assembled together and fixed to the wheelchair.*

The design criteria that were included as conceptual constraints were chosen on the basis of prioritization as selected by the occupational therapy environment.

Now with these constraints 'in-mind', the conceptual space for the problem was defined. All knowledge templates that were related to these constraints and the problems were automatically placed within the conceptual space.

Many of the templates were developed through familiarization. Other templates existed before familiarization. Templates that were formed during familiarization and were applied to the conceptual space include knowledge of all environments:

- *Clients and users*
- *Occupational therapy*
- *Geriatrics*
- *Assistive Technology (wheelchair knowledge)*
- *Legality*

Examples of templates that were already available to me include:

- *Engineering: physics, electronics, chemistry, CAD, mechanisms, components, etc.*
- *Manufacturing: availability of labor and machines, materials, manufacturing processes, time, cost, etc.*
- *Contractual: budget, scheduling, legal agreements, intellectual property, etc.*

As shown in figure 11, the brain automatically created the conceptual space and applied the relevant templates. However the combined knowledge did not cover the entire concept space. The mental struggle to find a solution ensues. The mind tries to simultaneously find the solution in three ways:

- by searching the given knowledge;
- by urging the designer to do more research to fill the knowledge gaps left on the concept space;
- by trying to modify the concept space by either removing a barrier or matching concept space knowledge with an unrelated template.

Several ideas emerged but were not pursued due to discouragement from the analytical side of the mind. Ideas such as the *variable center of gravity mechanism* and the *automatic outriggers* are described in the mechanical solution section of the report in the Appendix B. Included in the report are reasons against pursuing these ideas.

The idea for the solution eventually came when I realized that a certain constraint created unnecessary barriers. The barrier evolved from the design constraint that was a direct OT requirement: *devise must not interfere with surroundings.* Such a statement invokes a mental ban on all outrigger and laterally protrusive devices. From experiences with wheelchairs, one knows that overall width is a factor. With lateral outriggers, the wheelchair cannot pass through doorways or maneuver in tight spaces. Therefore anything that adds width is undesirable. My conceived mental barrier was that outriggers could not be incorporated into the solution.

Still, an outrigger would be a very simple, effective and elegant way to solve the lateral tipping problem. So I entertained the thought of modifying the 'no interference with surroundings' constraint. What if the outrigger was made in such a way that would permit wheelchair passage through doorways and side obstacles?

Once the 'no outrigger' barrier was removed (figure 12b), a new conceptual space was created. The new concept space contained outriggers and other mechanisms, such as the quick-return spring-loaded mechanism idea. This 'spring-load' concept was adopted in conjunction with the outriggers to create the spring-loaded anti-tipper solution. Not only does this devise prevent lateral tipping but also it permits the wheelchair to pass doorways. A full description of the devise is found in the Appendix B.

By removing the preconceived personal boundary, I was able to generate an innovative solution. It was creative because it was unexpected, counter-intuitive, and paradoxical in nature. The idea was brought into existence and implemented as a functional solution.

The solution is innovative on a conceptual level because both the spring-return and outrigger concepts are known. To my knowledge, this is the first attempt, at bring these two 'unrelated' concepts together as part of a solution.

Creativity has allowed me to produce a solution that is pragmatically inventive and conceptually innovative. It is an invention because not only is this the first solution for this problem but also it is the first successful attempt at finding a solution.

The Non-mechanical Solution

To generate a non-mechanical solution, I had to work with the same concept space that was used in the mechanical case. Same concept space was created but I needed to match a template that was the inverse of what has been laid out. All the constraints force the designer toward a mechanical solution. I needed to find something opposite.

One form of creatively exploring opposing ideas is called Janusian thinking (Middendorf, 1981). Janusian thinking, named after Janus the Roman two-faced god, deals with trying to find the negation of the conceptual space or an antithetical template. It is very similar as the figure 12a, because one still needs to find a link with an unrelated template. I had to negate all thought leading to a mechanical solution. In this sense the negation was also a constraint.

The answer was found by making a connection between the knowledge contributed by the occupation therapy/wheelchair user templates on the concept space with an ergonomics template. The idea of a *wheelchair 'envelope'* was born. It combined the awareness knowledge of the OTs with the notion of personal functional space, while at the same time avoiding any mechanical intervention. A full description of the wheelchair envelope is found in the Appendix B.

What makes this solution remarkable was the fact that it was totally unexpected. Every member of the multidisciplinary network expected me to solely develop a mechanical solution. Yet still a possible preventive answer lies in the occupational therapy-wheelchair user environments, rather than from pure mechanical engineering.

Summary of Revised Solutions

The solution to this problem was sought on different levels and using various perspectives. Naturally, given the background of the investigator, a mechanical approach was first taken. The mechanical design took into account the physical, financial, and social constraints to meet the needs of the user and staff. These needs were translated into feasible technological reality. The mechanical device that was produced is a:

- *Spring Loaded Lateral Anti-Tipper.*

Also a solution was sought on an administrative level. This approach considered the needs of the user, the implementation of a mechanical design, identification of potential users, user space, and recommendations of actions that would prevent lateral tipping.

All mechanical and non-mechanical solutions are found in the Appendix B in full detail.

Chapter Six
Conclusions

The formulation of a problem is often more essential than its solution, which may be merely a matter of mathematical or experimental skill.

Albert Einstein & Leopold Infeld, The Evolution of Physics: The Growth of Ideas from Early Concepts to Relativity and Quanta.

Einstein's statement summarizes the essence of engineering design as treated by this thesis. The ability to formulate an adequate design problem is the purpose of engaging in the familiarization phase of design activity. All actions executed during familiarization are intended for the engineering designer to discover the true problem to be solved.

Engineering education regulatory bodies have recently placed pressure on academia to develop quality design engineers. There are consistent demands to have innovative and knowledgeable junior engineering designers in Canadian industry.

Unfortunately, since the Grinter Report of the 50's, engineering education has tended to pursue a mathematical and scientific approach to design. In such a system all information gathered and all ideas generated must be processed through an established procedure. Engineering education has become procedural and this attitude has been reflected in its treatment of design.

The mechanistic approach to engineering design education as presented by the Grinter report downplayed the role of creativity and ignored the need for a multidisciplinary platform and the assessment of problem needs and goals. The designs that were being produced in engineering schools were not creative or satisfactory solutions to problems. They were academic, simplistic outcomes of a procedure rather than a meaningful experience.

In reality, problems do not always conform to a procedure. Real life engineering design problems tend to be open-ended and ill defined. Algorithmic and deterministic methods can not be readily applied to the majority of such cases. This may explain why engineering design education has either trivialized design or avoided such problems altogether.

The results are that junior engineers face industry with limited perspectives. They tend to produce solutions that are unimaginative, uncreative and lack originality. Moreover, they face difficulties adapting to unfamiliar environments or industries outside their engineering disciplines. They are challenged when trying to solve problems on different levels of a multifaceted industry.

In response to this alarming lack of innovation and professional flexibility, engineering schools have are now introducing seemingly unorthodox measures into their curricula. Given the multidisciplinary nature of design project, it is appropriate to take an approach that is different from the existing engineering design methods. The contemporary approaches include a blend of iterative stages, divergent thinking, creativity and a need assessment. In essence academia is attempting to introduce concepts that have been traditionally omitted or annulled.

Due to the lack of experience and procedure in presenting the concepts of creativity or holistic design, academia may face the challenge of effectively developing potential design engineers. Educators should have a better understanding of these new design perspectives in order for them to meaningfully instill such comprehension within the minds of engineering pupils.

The two most significant concepts in the contemporary view of engineering design are *creativity* and what can be termed as *familiarization*. Both these concepts can be viewed as instruments to foster innovation and develop holistic design engineers. Both concepts integrate facets from fields that are extraneous to engineering. Moreover, neither concept has an established set of instructions or procedures to follow. For this reason a thesis of this nature was warranted to enlighten educators and potential design engineers of the issues and facets involved in both creativity and familiarization.

Creativity was presented as a phenomenon that draws from the fields of psychology, neurology and philosophy. Creativity is not as abstract of a notion as most people perceive it to be. Creativity is a function of real constraints, existing knowledge and mental perseverance. It is something that can be developed and trained, and used readily in all problem-solving situations. It is particularly useful in engineering design because it sets the course for solution searching and it helps find and 'create' a meaningful solution.

This thesis demonstrated the necessity of taking the familiarization approach to multidisciplinary design. Based on methods from industrial design, architecture, marketing, management and manufacturing, this approach enables the designer to enter an unfamiliar client-user environment. Through the activities of need assessment, the formulation of a multidisciplinary platform, translation of user languages, abstraction, and the application of creativity, the real design problem can be defined. The engineer can work with clients of a different industry, identify their needs, and solve their problems on their level.

Innovative engineering design solutions are solutions that are not only original but also address the true needs of the client/user. Creativity and familiarization have been presented as two concepts that are complementary to the existing engineering design methods. Both satisfy the criteria for innovation and both take engineering design to a new level.

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- Sunrise Medical
- Skyway
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- Convaid Products Inc.
- Otto Bock Rehabilitation
- Maple Leaf Wheelchairs

Vendors

- Disabled Dealer Enterprises
- Cleavers Mobility Center (UK)
- Sammons Preston Ability One
- CARE4U-Aides to Daily Living
- MADDAK Aid to Daily Living
- Home and Health Care
- Medichair
- Home Care Medical Supply Center
- All-Care Medical
- A-1 Wheelchairs

- Abbey Medical Suppliers Ltd.
- Gold Care Medical
- ECO Medical Equipment

Standards and Legal Organizations

- Rehabilitation Engineering Society of North America
- International Standards Organization
- Alberta Aids to Daily Living

Databases

- ABLEDATA
- Medline

Disability Research Centers

- Rehabilitation Engineering Research Center on Wheeled Mobility
- Dr. RL Kirby, Dalhousie University
- Special Interest Group: Wheeled Mobility and Seating
- Center for Health Care Information

Geriatric Societies and Long Term Care

- The American Geriatric Society
- American Association of Homes and Services for the Ageing
- Wayne State Institute of Gerontology
- Canadian Red Cross
- International Institute on Health and Aging, University of Bristol UK
- Age and Ageing

Patent Searches

- US Patents
- Canadian Patents

Conferences

- Medtrade 97

Bethany Care Society

- Kate Chidister
- Anne Todd
- Grace Rutledge
- Marlene Simmermon
- Bobbie, Jean, Deanna of the therapy department

Appendix A

Passive Wheelchair Brake System
First Term Report

Presented to the Bethany Care Society

By Ernest Baraniecki

June 24, 1998

June 24, 1998

Bethany Care Society
1001 -17 Street NW
Calgary, Alberta, Canada
T2N 2E5

Dear Society Members,

Please find attached to this letter a copy of the report entitled "Passive Wheelchair Brake System: First Term Report". This report fulfills the requirements of the University Technologies International Inc. and the Bethany Care Society agreement that a report is to be presented at the end of the first research term. The report contains the work, findings and conclusions of the study conducted in the area of passive wheelchair brake systems as part of a graduate project in the Department of Mechanical Engineering at the University of Calgary. Accompanying this report will be an oral presentation. If you have any questions or comments following the presentation date, I can be contacted at 220-4173.

Sincerely,

Ernest Baraniecki

Attachment

Executive Summary

A problem in wheelchair braking has been brought forth to the University of Calgary. The initial request was to develop a braking system for a wheelchair that would immobilize the wheelchair when it came to rest, and permit mobility of the wheelchair when desired. Initially the most reasonable solution to this problem seemed to be the design of an Automatic Park Brake (APB) system for the wheelchair. However, it became evident during the course of the investigation that actual problem is wheelchair stability. The stability problem is more closely related to wheelchair tipping than it is to braking. More research is needed in the area of wheelchair tipping, and it is expected that a design to satisfy the wheelchair needs of the residents and staff of the Bethany Care Center can be implemented within a year's time.

Table of Contents

1. Scope of the Research

1.1 Introduction

In December of 1996 W.K. Dickson, an advisor and benefactor to the Bethany Care Society, submitted a proposal to the Mechanical Engineering Department at the University of Calgary. In it, Mr. Dickson identified a problem with wheelchairs as used by the clients of Bethany Care Center. At that time he felt that the problem with wheelchair accidents was related to the park brake that is integral to every manually propelled wheelchair. Specifically, he encouraged the idea of designing and developing a park brake that would automatically engage and release. According to Mr. Dickson such a devise would contribute to his primary objective of Improving the Quality of Life of the Seniors and Disabled Residents of the Bethany Care Center.

1.2 The Initial Statement of Problem

Both the Bethany Care Society and the University of Calgary agreed that there is enough merit to warrant a further investigation of the problem. The University of Calgary, University Technologies International and the Bethany Care Society entered into an agreement to investigate the area of the "passive wheelchair braking system". The project would be undertaken by a mechanical engineering graduate student as part of his master's thesis in the field of design. The duration of the project is expected to two years divided into one year terms. In the first term the investigation of the problem would be carried out and the findings are to presented to the members of the Bethany Care Society. It would be then the decision of the Bethany Care Society whether or not to pursue the project into the second year. The second year of the project would be designated for the design and development of a solution.

1.3 Initial Need

My understanding of the situation was that problems resulted when wheelchair occupants were left unattended without the park brake being applied. Due to a slope in the terrain or the influence of an unexpected force, the chair would roll off and possibly tip over, ejecting the occupant. As a result of these accidents the wheelchair users sustained injuries ranging from bruises to serious facial trauma. The reasons for not applying the park brake include human error on the part of the care-giver, the physical inability of the wheelchair occupant to apply the brake due to arthritis or paralysis, or the forgetfulness of the user due to some form of dementia. In addition it was thought to be beneficial to the care-giver for not having to apply the brake each time the wheelchair came to a stop enabling the care-giver to focus his/her efforts on the needs of the resident rather than the brake.

1.4 The Braking System Constraints

It was initially proposed that the solution to these problems was the development of a passive braking device for the wheelchair. The nature of this device would be such that when the motion of the of the wheelchair comes to a stop, the park brake would automatically engage and immobilize the wheelchair. When mobility of the wheelchair is desired the brake system would have to automatically release itself. The wheelchair should remain immobilized between a range of gradients in terrain in both indoors as well as outdoors. Furthermore, this device or system, should not alter the normal performance of the wheelchair, nor should the wheelchair be physically altered to accommodate this system. The system would have to be adaptable to a variety of existing wheelchairs. The system must also ensure the safety of the user and care-givers, meaning it would have to be fail safe and fool proof. Also the cost of design and development would have to be kept to a minimum in anticipation of mass manufacturing of the product.

2. Findings

2.1 Investigation of the Problem

The initial research of the project began with three goals in mind: 1) the establishment of a definite need; 2) formulation of a problem statement; 3) generation of ideas for a passive wheelchair braking system. This section of the report identifies and elaborates on the various steps that were taken in pursuit of these goals. Due to the interdependence these steps, they are not listed in chronological order as some were carried out simultaneously while others at different times. Findings are presented with each investigation activity. These findings influenced the initial three research goals and hence the future of this project.

2.2 Incident Reports

A key to approaching the goal of need establishment was the gathering information from past incident reports at the Bethany Care Center (BCC) as well as finding existing studies in this field. Monthly incident reports over the past four years at the BCC were studied.

- On average approximately two to three brake related accidents occur each month.

Most of these occur as a result of transferring to and from the wheelchair with the park brakes not being applied. Specifically, when the brakes are not applied and the occupant tries to get up or sit down, the wheelchair will roll away backwards from the occupant. This will result in either a fall or an uncomfortable position (when getting in). The types of injuries that occurred ranged from bruises to lacerations. However, it is difficult to give exact figures, times and types of accidents and associated injuries as the incident reports are not statistically tabulated at the BCC.

- While looking for brake related incidents, it was discovered that there are about two and half times more wheelchair tipping and falling accidents then there are braking accidents.

This leads to the realization that perhaps efforts should be focused on a different aspect of the wheelchair stability problem - wheelchair balance.

2.3 Literature Searches

A literature search on the subject of wheelchair brake accidents, wheelchair safety and work being done to improve safety yielded little relevant information. Since most of the work has been done in the 90's. Dr. R. Lee Kirby, MD of Nova Scotia Rehabilitation Center is a leading investigator of wheelchair safety and improvement. His research in this field has generated disturbing results. In the U.S., 52 fatalities occurred and 37 000 people needed treatment per year due to wheelchair accidents. Recently this figure has risen to 50 000 persons seeking treatment in emergency rooms. Other injury records are presented in the appendix. Statistically the Canadian figures are worse than those of the U.S. due to current practices, funding and government regulations. A wheelchair in Canada is not considered a medical device, as it is in the U.S. Therefore accidents are frequently not reported or tabulated, and building safety codes are ignored. Further contributing factors to the accidents are various design flaws in such areas as the weight of the chair, how it's set up and adjusted, the relationship between the front and rear wheels, and whether there's a backward tilt to the chair. Apathy toward a safe product, where safety issues become a low priority due to the costs in implementing them. From a manufacturing perspective, manufactures must be prepared to take on the costs of implementing safer designs. The cost will of course be passed on to the consumer.

- Brake related accidents represent less than 20% or the total wheelchair accident in the US, with Canadian data being unavailable.
- The most common accidents are due to tips and falls accounting for 68.5% of the fatal and 73.2% of the nonfatal accidents. Due to various reasons Canadian figures have been harder to find, but one study in Nova Scotia showed that 1 in 20 people will experience a tipping accident per year.

2.4 Observations

Several visits to the BCC were conducted to observe the times when a wheelchair stops when existing park brakes need to be applied, the motions of the wheelchairs and the motions of the occupants. It was observed the park brakes are most commonly applied when the resident needs to be transferred to and from the wheelchair. Reasons for transfer include going to bed, being place in a comfort chair, bathroom usage, exercise and physiotherapy. There are also several different types of transfers: independent, dependent on one aid, dependent on two aids and mechanical transfer. These are due to the varying needs, strengths and abilities of the user. In almost all cases the park brakes have to be applied by either the user or the care-giver. It would appear to be an aid if the wheelchair would automatically immobilize itself for these cases. There are also the non-transfer cases when an automatic park brake (APB) would be desired. These include: sitting in one place and having the wheelchair subjected to an unexpected force; leaning forward or reaching for something; and if the occupant is not sitting in the chair but holds the handle or arms for support. The concern for parking wheelchairs on sloped indoor floors has already been addressed by the BCC as all slopes are now wheelchair inaccessible. If an APB was to be designed a lot of consideration must be given to the various forces exerted by the occupant on the chair. The diversity of the occupants conditions, behavior and motions during transfer, renders a universal APB unrealistic.

2.5 Product Searches

In order to determine if an APB device already exists in the market, patent searches were carried out and medical equipment sales representatives were consulted. One location to conduct a product search was at the 1997 International Medtrade Show held at New Orleans, Louisiana. This is one of the largest trade shows of it's kind where over a quarter million medical and rehabilitation products from over 100 countries were displayed.

- An extensive search of all the major medical equipment companies like Sunrise Medical, Invacare, Everest & Jennings, Kuschall of America etc. has generated absolutely no existing or competitive products that would satisfy the automatic park brake requirement.

In fact most manufactures did not consider this to be a issue claiming that any braking problem is due to the operator error. Most of these companies preferred to focus on performance than overall safety in their products. Medical equipment retailers were also interviewed. They never heard of an APB device. The information gathered from the medical equipment manufactures and vendors is reason to indicate that the APB concept is unique and that if it were to be developed it would enter a market without competition. To verify this notion a patent search was conducted.

- Anti-tipping devices on the other hand are a familiar concept to wheelchair manufactures and dealers.

2.6 Patent Search

Both the Canadian and American patent offices were extensively searched for any information about brakes and especially the APB. The Canadian patent office offered nothing.

- Over 20 wheelchair brake related patents were ordered from the US patent office. Of those two were officially designed as Automatic Wheelchair Park Brakes.

Studying the designs and their claims two problems immediately emerged. Firstly, in both designed the braking function was transfer-actuated. Transfer-actuated refers to the method used to initiate the brake action. The method in all cases is the action of transferring. In other words the brake only engages when the user is being transferred off the vehicle, and latter the brake releases when the occupant is placed back in the wheelchair. The transfer-actuated APB is not a sufficient solution for this project since immobility of the wheelchair is desired not only during transfers but also whenever it comes to rest for any other previously mentioned reason. The questions that this scenario poses is "how will the braking system know that the wheelchair has stopped in order to engage and how will it know to release the wheelchair when mobility is desired?" A mechanical solution to this problem has yet to be found. The second problem that the patented APB systems presented is that both required modification to the existing wheelchair. Again, this is an undesirable characteristic as the existing wheelchairs at the BCC can not be altered. Not only is this a government regulation as specified by the Alberta Aids to Daily Living (AADL) policy, but also alteration to wheelchairs would run the risk of compromising the safety of the use.

- Over 30 wheelchair patents mention the inclusion of anti-tippers. 3 patents were devoted exclusively to the anti-tipping problem.

2.7 Interviews

Dr. Kirby MD of Nova Scotia, one of the principle investigators of wheelchair accidents and improvement was contacted on several occasions. He has also worked on a similar project 1995. The unpatented APB design that his team developed has the same undesirable characteristics as the existing patents. These being modifications to the wheelchair and the transfer-actuated brake application. Dr. Kirby maintains that the problems of wheelchair stability have had low priority manufacturing community but are becoming increasingly important. Especially problems related to tipping. Anne Todd, the director of therapy at the BCC, expressed the greatest concern with regards to the project. In her words the APB would be more of a hindrance than a help, and if a successful design was to be developed it would aid only a very specific portion of the population under a specific set of circumstances. A universal design is highly improbable at this point. In Anne Todd's view, a view that she has held throughout the duration of the project, is that any effort aimed at aiding and improving wheelchairs and their occupants should be focused on tipping prevention rather than the APB. Independently supporting this view is Kate Chidister, the director of reports, who in a September 1997 interview said there are definitely more wheelchair tip over accidents than those related to braking.

- Based on the interviews APB is either moderately desirable or insignificant.
- An anti-tipper is recommended by everyone based on a definite need.

2.8 Idea Generation

As a method of generating ideas for a design a technique called brainstorming was employed. A senior mechanical engineering design class was called upon to perform a brainstorming session. The posed problem was that of a passive brake system for a wheelchair. Approximately 280 ideas were generated representing a wide range of concepts. As this project progresses and develops a definite design direction, this database of ideas can be readily employed to establish conceptual designs.

3. Future

3.1 The Problem Redefined.

What began as a problem of wheelchair braking has developed into a problem of wheelchair stability. The findings of the past research indicate the following three issues. Firstly, there really is a problem with wheelchairs that needs to be rectified. Secondly, it is problem of stability that appears to be related to tipping and balance. Thirdly, any successful attempt at solving this problem would satisfy the BCS objective of improving the quality of life the senior and residents.

3.2 Further Investigation.

Since the nature of the problem is shifting towards tipping rather than braking, further investigation of tipping is warranted. Already the issue of tipping has surfaced many times through the initial problem investigation. Tipping information has been collected wherever necessary. However more time is needed to investigate the tipping situation in order to make the understanding of the stability problem more complete. Patent searches, literature searches, more interviews with Dr. Kirby and the staff of BCC, and observation of wheelchair use are all required to redefine the problem comprehensively and establish a definite direction of design.

3.3 Development of a Design.

Once the needs have been determined they can be translated into design constraints. It is the intention of the researcher to design a product, manufacture it and apply it to solve the problem. All the drawings, analytical data, procedures, engineering information, and manufacturing techniques will be presented to BCS. Development of this information will take up the remainder of the second work term.

4. Conclusions

An initial investigation in the field of passive wheelchair braking was carried out. The findings lead to the conclusion there are problems associated with wheelchair stability, however these problems are more akin to wheelchair tipping rather than wheelchair braking. It is highly recommended more efforts are focused on the problems of tipping than braking. Since tipping is the cause of more accidents, a solution to tipping would offer more toward the improvement of the quality of life of seniors and disabled residents at the Bethany Care Center. I am prepared to pursue either the brake problem or the tipping problem for the next year, depending on your decision.

Contact

If there are any further questions or concerns regarding the report, presentation, or the project please contact me at:

Ernest Baraniecki
Mechanical Engineering
University of Calgary
2500 University Drive NW
Calgary, Alberta, Canada T2N 1N4

Tel: (403) 220-4173
Fax: (403) 282-8406
Email: baraniec@enme.ucalgary.ca

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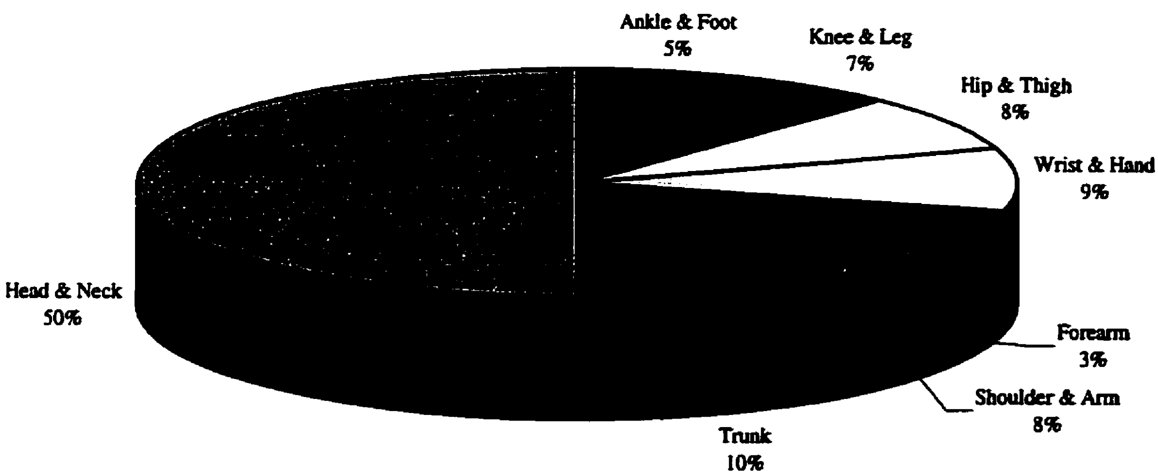
I would like to thank the Bethany Care Society for their support and funding for this project. I also grateful to following people from the BCC for their help and input:

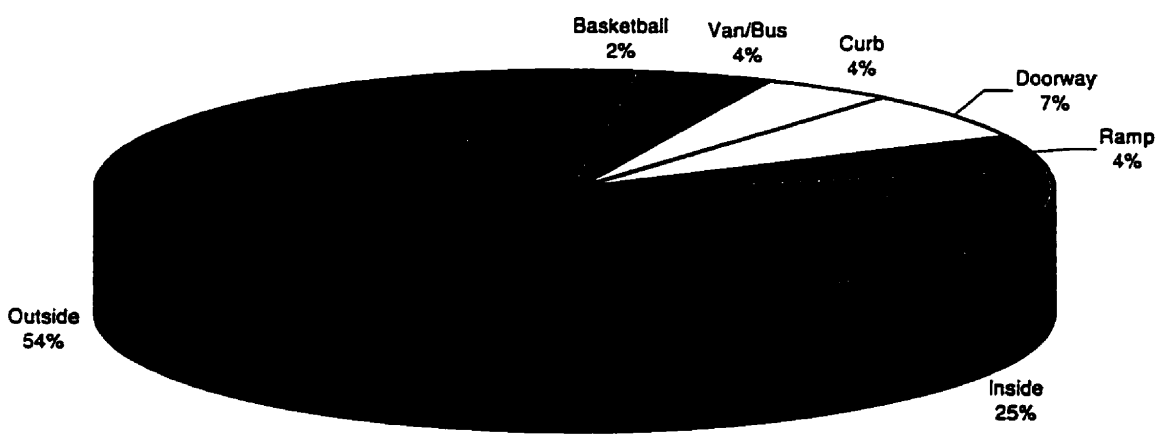
Kate Chidister
Marelene Zimmerman
Grace Rutldge
Anne Todd
Bobbie, Jeane, Deanna of the therapy department

Appendix

Body Parts Injured



Where Accidents Occurred



Appendix B

Wheelchair Stability Assessment

The Final Report

Ernest Baraniecki
University of Calgary Mechanical Engineering

June 30, 1999

Executive Summary

Many senior wheelchair users experience stability problems. These problems can cause accidents that result in serious injuries and even death. The population of seniors is growing, so is the number of mobility limited elders and the wheelchair accident rate is increasing. The wheelchair user at the Bethany Care Center also has a significant amount of accidents. Therefore an investigation into the area of wheelchair stability was warranted. The purpose of this investigation was to develop and propose mechanical and non-mechanical solutions that would address the main goal of the Bethany Care Society: To improve the quality of life of the seniors and disabled at the Bethany Care Center.

The investigation encompassed a wide range of wheelchair associated issues. These included a study of wheelchair-related accidents, analysis of wheelchair stability, managerial considerations, guidelines related to identification of user needs and prescription of technology to satisfy user needs.

Once the investigation was completed and an overview of the situation was presented, several solutions to the problems of lateral stability were proposed. The mechanical solution is a spring-loaded lateral anti-tipper, which was designed to prevent tipping in the lateral direction while not impeding wheelchair mobility. The non-mechanical solutions include staff education, development of an information system, enforcement of wheelchair prescription, and the recognition of each user's wheelchair envelope. The wheelchair envelope is the area in which each wheelchair user should perform any task or activity, attempting an action beyond the envelope can result in an accident.

It was the intention of the investigator to provide an overview of the issues and considerations involved in addressing the problems of wheelchair stability. The suggested solutions are designed to alleviate and prevent stability problems. The implementation of these solutions and incorporation of the information presented here into the Bethany Care Center is under the discretion of the BCC administration.

Abstract of Report

Due to the lengthiness of this report some many choose to read the chapter summaries as presented here and/or go to the sections of their interest.

Overview of the Problem

- The initial investigation was focused at developing an automatic park brake.
- It was discovered that user's had serious stability needs.
- The investigation refocused on the lateral instability situation.
- Both mechanical and administrative solutions have been proposed.

Wheelchair Design and Selection Issues

- All potential mobility base equipment users have needs.
    - Physical
    - Mental
    - Social
    - Financial
    - Political
- Needs must be determined by a multidisciplinary team:
    - User
    - User Associates
    - Caregivers
    - Occupational Therapists
    - Doctors
    - Rehabilitation Engineers
    - Physiotherapists
    - Management
- All wheelchair equipment and accessories must be prescribed to that particular user.
- Prescription involves a thorough evaluation of the user's situation and unsatisfactory condition.
    - User's Medical History
    - User's Social History
    - Physical Examination
    - Mental Examination
    - User Skills
    - External Environment
- Prescribers must be aware of wheelchair characteristics
    - Components
    - Standards
    - Design Criteria

- Prescribers and designers must translate the needs of the user into technological reality.
- Any prescribed equipment in Alberta is currently subject to the scrutiny of the AADL.

Epidemiology of Falls

- Causative factors in elderly falls are interdependent. They include:
  - Postural stability
  - Light
  - Health
  - Location
  - Reaction Time
  - Time and Date
  - Drugs and Alcohol
  - Mental Status
- Wheelchair accidents have the following characteristics:
  - Number is steady growing.
  - Most accidents happen in the senior population.
  - Most wheelchair fatalities occur in the senior age group.
  - Fatalities mostly happen at institutions.
  - Lacerations are the most common injury.
  - The head is the most common part of the body to get injured.
  - Majority of fatalities are due to skeletal system injuries.
  - Wheelchair tips and fall are the usual nature of accident.
- All accidents must be reported at the BCC.
- Emphasis should be placed on the completeness and descriptiveness of report.
- All reports should be organized and processed statistically for easy reference.
- The majority of all wheelchair accidents, within or external to the BCC, are tip-fall in nature.
- Postural stability is a major causative factor for most elderly falls
- Overall stability of the wheelchair-user system is the greatest issue wheelchair design.
- Injury prevention depends greatly on the individual's ability to use the wheelchair safely. Although the design, components and appearance of wheelchairs continue to improve, more attention should be paid to injury prevention in future design and improvements.

Stability

- A body is considered stable when its center of gravity is above its base.
- Stability of wheelchair user can be divided into two categories:
  - Stability of the individual
    - General stability
    - Sway

        - Postural stability in the chair
        - Functional stability in the chair
    - Stability of the user-wheelchair system
        - Structural stability
        - Static
            - Anterior
            - Posterior
            - Lateral
        - Dynamic
            - Anterior
            - Posterior
            - Lateral
            - Directional
- Interventions should be aimed at teaching appropriate transfer techniques, providing adequate staff to assist with transfers, a maintenance program for wheelchairs, and individually prescribed wheelchairs.
- Wheelchair design, in terms of front castor size, anti-tip roller bars, center-of-balance adjustments, etc., should be customized according to the individual's disability/ability.
- Excessive wheelchair stability may hinder performance

Management Issues

Wheelchair related accidents are common and many are potentially avoidable. Injuries to wheelchair occupants and attendants could be prevented by:

- Regular wheelchair maintenance.
- Administrative process geared at achieving well-defined goals.
- Identification and understanding user needs.
- Improved education for wheelchair attendants on how to erect and dismantle chairs and how to negotiate potential hazards such as curbs and steps.
- Early prevention program.
- Ensuring that the environment is made more 'wheelchair friendly'.
- Establishment of a multidisciplinary group, that is managed through occupational therapy:
    - Nursing
    - Maintenance
    - Inservice Education
    - Physical Therapy
    - Housekeeping
    - The Administration
- Effective communication between staff, residents and management.
- This report is aimed to be a source of educational information for caregiver staff.

Mechanical Solution

- The lateral stability needs of the users were recognized.
- Characteristics of the problem that were implemented in the design include:
    - Goals
    - Objective
    - Constraints
    - Main Criteria
- Concepts were evaluated with respect to the criteria.
    - Variable Center of Gravity
    - Automatic Outriggers
    - Lateral Anti-Tippers
- The Spring-Loaded Anti-Tipper design was chosen. Due to it's:
    - Safety
    - Functionality
    - Manufacturability
- The design prevents users from tipping their wheelchair and permits easy movement of wheelchair in its surroundings.
- The design can be implemented for anyone with postural instability, poor vision and depth perception, higher center of gravity and those that have a history of falls.
- The prototype has to be tested in a care home environment and evaluated.
- This device should only be prescribed to a resident upon a complete evaluation of their needs.

Non-mechanical Solutions

Possible policy solutions for lateral stability include:

- Prescription of all assistive devices.
- The recognition of a wheelchair envelope.
    - Envelope must be established for every user.
    - All user activities must within envelope.
    - Caregiver must be monitor areas of potential activities that can occur outside an envelope.
    - Any task done outside the envelope can be lead to a fall and injury.
- Information collected and processed efficiently.
    - Incident reports.
    - Equipment inventory.
    - Employee surveys.
    - Evaluation of the facility.
- Education of the staff about wheelchair issues and safety.
    - Knowledge of wheelchair issues.
    - Understanding user needs.
    - Wheelchair maintenance.
    - Identification of problem locations and accident potential activities.
    - Procedure manual.

Table of Contents

List of Figures

Overview of the Problem

Introduction

In December of 1996 WK Dickson, an advisor and benefactor to the Bethany Care Society submitted a proposal to the Mechanical Engineering Department at the University of Calgary. In it, Mr. Dickson identified a problem with wheelchairs as used by the clients of the Bethany Care Center. At that time he felt that the problem with wheelchair accidents was related to the park brake that is integral to every manually propelled wheelchair. Specifically, he encouraged the idea of designing and developing a park brake that would automatically engage and release. According to Mr. Dickson such a device would contribute to his primary objective of "Improving the Quality of Life of the Seniors and Disabled Residents of the Bethany Care Center."

Initial Problem Statement

Both the Bethany Care Society and the University of Calgary agreed that there is enough merit to warrant a further investigation of the problem. The University of Calgary, University Technologies International and the Bethany Care Society entered into an agreement to investigate the area of the 'passive wheelchair braking system'. The project would be undertaken by a mechanical engineering graduate student as part of his master's thesis in the field of design. The duration of the project is expected to be two years divided into one-year terms. In the first term the investigation of the problem would be carried out and the findings are to be presented to the members of the Bethany Care Society. It would be then the decision of the Bethany Care Society to pursue the project into the second year. The second year of the project would be designated for the design and development of a solution.

Initial Need

The investigator's understanding of the situation was that problems resulted when wheelchair occupants were left unattended without the park brake being applied. Due to a slope in riding surface or the influence of an unexpected external force, the chair would roll off and possibly tip over, ejecting the occupant. As a result of these accidents the wheelchair users sustained injuries ranging from bruises to serious facial trauma. The reasons for not applying the park brake include human error on the part of the caregiver, the physical inability of the wheelchair occupant to apply the brake due to arthritis or paralysis, or the forgetfulness of the user due to some form of dementia. In addition it was though to be beneficial to the caregiver for not having to apply the brake each time the wheelchair came to a stop enabling the caregiver to focus his or her efforts on the needs of the resident rather than the brake.

Initially Desired Solution

It was initially proposed that the solution to these problems was the development of a passive braking device for the wheelchair. The nature of this device would be such that when the motion of the wheelchair comes to a rest, the park brake would automatically engage and immobilize the wheelchair. When mobility of the wheelchair is then again desired the brake system would have to automatically release itself. The wheelchair should remain immobilized between a range of slopes of riding surface in both indoors and outdoors. Furthermore, this device or system should not alter the normal performance of the wheelchair, nor should the wheelchair be physically altered to accommodate system. The system would have to be adaptable to a variety of existing wheelchairs. The system must also ensure the safety of the user and caregivers, meaning it would have to be fail-safe and fool proof. Also the cost of the design and development would have to be kept to a minimum.

Revised Need

The investigation commenced the first year. The primary objective of the investigator was familiarization with wheelchairs, the BCC and geriatric accidents. Upon interviewing professionals in these fields at the BCC, conducting literature searches, direct observation and contacting external organizations, it became evident that the needs of wheelchair users have to be redefined. It was discovered that:

- The automatic park brake was not particularly desirable.
- Most wheelchair related accidents were due to tipping and falling.
- There was no known solution to address the case of lateral tipping.

These three points have one thing in common: the issue of wheelchair stability. A user's need stems from an unsatisfactory condition in the user's life. The unsatisfactory condition observed was that user's are very likely to experience an accident due to wheelchair instability. Furthermore, falls occur in all directions: forward, backward and side. Although there are provisional solutions to anterior and posterior wheelchair instability, there aren't any solutions to the lateral tipping case. Therefore the need for finding a solution to lateral tipping arose.

Revised and Current Problem Statement

Upon approval of the Bethany Care Society to investigate the needs and problems associated with wheelchair instability, the investigation entered it's second year. All the literature studies and contacts made with industry professionals are found are listed in the reference section on this report. A serious effort was made to find information on the problems of lateral stability and sideways tipping problems. Based on this information the new problem statement was: "To find possible solutions to lateral wheelchair stability in a geriatric setting." The entire problem exploration was subject to the goals of the Bethany Care Society, the needs of the users, the constraints imposed by AADL, the criteria set by various professionals and considerations of the user/caregiver environments. All these design characteristics will be discussed in greater deal in the design chapter of the report.

Revised Solutions

The solution to this problem was sought on different level and using various perspectives. Naturally, given the background of the investigator, a mechanical approach was first taken. The mechanical design took into account the physical, financial, and social constraints to meet the needs of the user and staff. These needs were translated into feasible technological reality. All these considerations will be discussed at length in the design section. The mechanical device that was produced is a:

- *Spring Loaded Lateral Anti-Tipper.*

Also a solution was sought on an administrative level. This approach considered the needs of the user, the implementation of a mechanical design, identification of potential users, user space, and recommendations of actions that would prevent lateral tipping.

Summary

- The initial investigation was focused at developing an automatic park brake.
- It was discovered that user's had serious stability needs.
- The investigation refocused on the lateral instability situation.
- Both mechanical and administrative solutions have been proposed.

Wheelchair Design and Selection Issues

Identification of Users and Types of Wheelchairs

Wheelchair users are can be divided into three groups (Wilson, 1992):

1. *Persons who have lost lower-limb function owing to*: spinal-cord injury, arthritis, cerebral palsy, poliomyelitis, multiple sclerosis, muscular dystrophy, stroke and brain trauma, or bilateral amputation.
2. *Persons with insufficient postural stability owing to*: brain damage, cerebral palsy, or cancer of the spine.
3. *Persons with general debilitation owing to*: aging, alcoholism, or temporary illness.

The principle types of wheelchairs used for these individuals are:

- *Conventional, Standard* or *Basic*: are manual wheelchairs using a folding frame with an X-shaped linkage and telescoping tubes. The large driving wheels are usually in the rear with smaller caster wheels in the front. Rarer wheelchairs with large wheels in the front are called traveler wheelchairs. The adult model with footrests weighs 30 pounds or more.
- *Lightweight*: are standard manual wheelchairs modified to reduce the overall weight. Most do not have an X-frame but a solid axle.
- *Racing, Sport* and *Ultralight*: are manual lightweight wheelchairs modified for athletic activities and an active lifestyle.
- *Powered*: are wheelchairs driven by electric motors that use storage batteries.

The topic of wheelchair design and selection is very broad. For the sake of simplicity and conciseness the following discussion focuses on conventional manual wheelchair issues with respect to the elderly user.

Needs

The foundation of selecting or designing a wheelchair or a device for a wheelchair is the identification of the users needs. A good understanding of the needs, desires, and capabilities of individuals with disabilities is critical if rehabilitation workers are to promote optimum quality of life (Fisher, 1993). A need is a derivative of an unsatisfactory condition. Usually this condition is composed of a system of factors. They could be physical, financial, social, legal, mental, and environmental. The most difficult part to provide an appropriate solution to address the individuals needs. Most of the time the solution comes in the form of technology, an assistive device. The solution can, however, be found in politics, the law, and the administration of a care-home.

Provision of appropriate technology is a complex and time-consuming process requiring skilled, multidisciplinary assessment, discussion, and clinical trail of range of available equipment. This ensures that the equipment provided is desired by the person, meets the changing and complex needs of the individual, and is within the available budget of the person or the service.

One of the problems facing technology-oriented solutions is that there is no device that can aid everyone. There is no 'typical user' and a wide range needs to be catered for. Furthermore, user requirements do not remain static, but change with aging or increasing disability. Often the technology provided to the disabled is inadequate, or addresses the wrong need. A common pattern of adoption and abandonment of devices (Batavia, 1990) develops:

1. The disabled individual is provided an assistive device through a clinically aided or personal selection process.
2. The individual uses the device and recognizes that it is inadequate to meet their needs for one or more reasons, even after attempted modifications.
3. The individual either continues to use the device, remaining dissatisfied with it until it is no longer usable, or abandons the device at an early stage
4. The individual then chooses another device that satisfies the needs the previous device failed to satisfy (but often fails to meet other needs)

One reason for this pattern is that the disabled consumer (or person who chooses the device on behalf of the consumer) often is not adequately aware of his or her own needs as they relate to assistive devices. To avoid this inefficient pattern, each person must be individually assessed and prescribed the optimal device.

Prescription

A thorough assessment must be carried out the caregivers, occupational therapists and physicians. The user must go through an evaluation process. The ultimate goals of this evaluation is a wheelchair or a wheelchair accessory that (Delisa, 1982):

- Meets the users needs safely
- Sized to allow proper alignment and comfort
- Fitted with accessories that permit maximum independence

The following are prescription guidelines and considerations (Ragnarsson, 1990; Batavia, 1998, Cooper 1998):

User's Medical History
- *Age*: Adjustable components may be needed for growth or physical recession.
- *Gender*: Center of gravity and fat distribution differences between men and women can require different postural requirements.
- *Height*: Tall and short patients may need high and low seat-level heights, respectively.
- *Weight*: Heavy users may need a heavy-frame construction.
- *Diagnosis*: The type of mobility base and postural support are based in part on the patient's level of physical impairment.

- *Prognosis*: The prognosis may determine whether the wheelchair is to be rented or purchased.
- *Surgeries*: Orthopedic surgeries can alter anthropometrics and postural needs.
- *Physical rehabilitation*: Gains in therapy can reduce equipment needs.
- *Medication*: Drowsiness due to medications can make power mobility unsafe.
- *Orthotics*: Additional space in wheelchair may be required.
- *Prosthetics*: May alter the center of gravity.
- *Systems review*: For thoroughness, do a chart review of major organ systems.

User's Social History

- *Residence*: Determine wheelchair accessibility and clearances.
- *Caregivers*: Availability of support to maintain equipment.
- *Indoor and outdoor use*: Consider durability of frames, shock absorption features, and appropriate power mobility needs for outdoor and rough terrain use.
- *Table surface requirements for work and eating*: Determine appropriate armrest style.
- *Travel*: Consider lightweight folding wheelchair for car transportation and storage; tie-down feature for bus travel.
- *Hours sitting*: Extended periods of time sitting can require a pressure cushion with greater pressure-reduction properties.
- *Age of existing wheelchair*: Equipment age may determine warranty period, suggests amount of wear, and clues the clinician as to when user was last funded.

Physical Examination

- *Passive Range of Motion*: Determine if user has sufficient lower extremity range of motion to fit into a standard wheelchair and upper extremity range of motion to reach handrims.
- *Anthropometric measurements*: Measure the user's seat depth, seat width, back height, and heel-to-knee distances to determine frame size.
- *Skin*: Determine risk for pressure-sore development and need for a pressure-reducing cushion, gravity assisted positioning, or both to redistribute pressure between user's buttock's and seat surface.
- *Sensation*: If user is insensate, a pressure-reducing cushion may be needed. If vision is diminished, power mobility may be unsafe.
- *Postural alignment*: If significant fixed asymmetric deformities of the truck or pelvis are present, custom-molded postural inserts may be required.
- *Active movement*: If no movement or weight-shifting ability is possible, consider a good pressure-reducing cushion. Pad wheelchair if activity-related injuries are possible.
- *Sitting balance*: Consider lateral and anterior trunk supports if balance is poor. Use reclining or backward tilt-in-space wheelchair to decrease reliance on anterior trunk supports.
- *Primitive reflexes*: Block movements that trigger undesirable reflex activity.
- *Tone*: Low tone may require reclining or backward tilt-in-space wheelchairs to discourage trunk collapse. Spasticity may require foot straps to maintain feet on

footrests. Extensor tone requires adequate pelvic stabilization.

- *Endurance*: A lighter weight, manual wheelchair or power mobility may be needed for patients with limited endurance.
- *Strength*: Improve propulsion efficiency if needed with lightweight frame and wheels, large handrims, camber rear wheels, optimized position of user relative to rear axis using multiple adjustable axis.

Mental Examination

- *Memory*: Memory is required to perform wheelchair procedures safely or avoid certain actions.
- *Cognition*: Intentional behavior to operate and use the device.
- *Perception*: Level at which the user's perceptual defects affect wheelchair mobility and safety.
- *Judgement*: Determine if user judgement is adequate for independent wheelchair use. The user may have to be supervised while in chair.
- *Motivation*: Determine if user is motivated to operate a wheelchair.

User Skills

- *Locomotion*: Unsafe or nonfunctional ambulation requires self-propulsion of a manual wheelchair. Nonfunctional ambulation requires a powered or attended operated wheelchair.
- *Transfers*: Evaluate appropriate seat cushion, front rigging and armrests.
- *Sitting*: A high back support may be needed for users with inadequate spinal support, decreased trunk control, and lower activity level in wheelchair.
- *Upper extremity function*: Evaluation ability to self-propel or operate power mobility switches and controls.

***External Environment*:**

- *Expectations*: Expectations of the family, friends, employers and caregivers.
- *Support*: Level of support and security provided by the family, friends and cohabitants.
- *Architecture*: Considerations of potential environmental barriers, and modifications of the surroundings for living.
- *Cosmetic features*: Aesthetic features that please the user and are socially acceptable.
- *Options available*: Consideration of other types of mobility bases that can also satisfy the user needs.
- *Cost*: Financial evaluation of user and benefactors with respect to desired technology.

Wheelchair Components

Part of the process of prescribing technology in order to match assistive devices with an individual's needs, is knowledge of the technology. The occupational therapist or rehabilitation specialist must be aware of the various components of a wheelchair as well as wheelchair accessories. This requires the identification of the major components as well as their respective functions. The may also require market knowledge: competitive products, options, costs, and availability.

The standard wheelchair is composed of over a dozen different components. Each one of these is an integral part of a system that must satisfy the users needs. A full system of standard wheelchair components is presented in Figure 1.

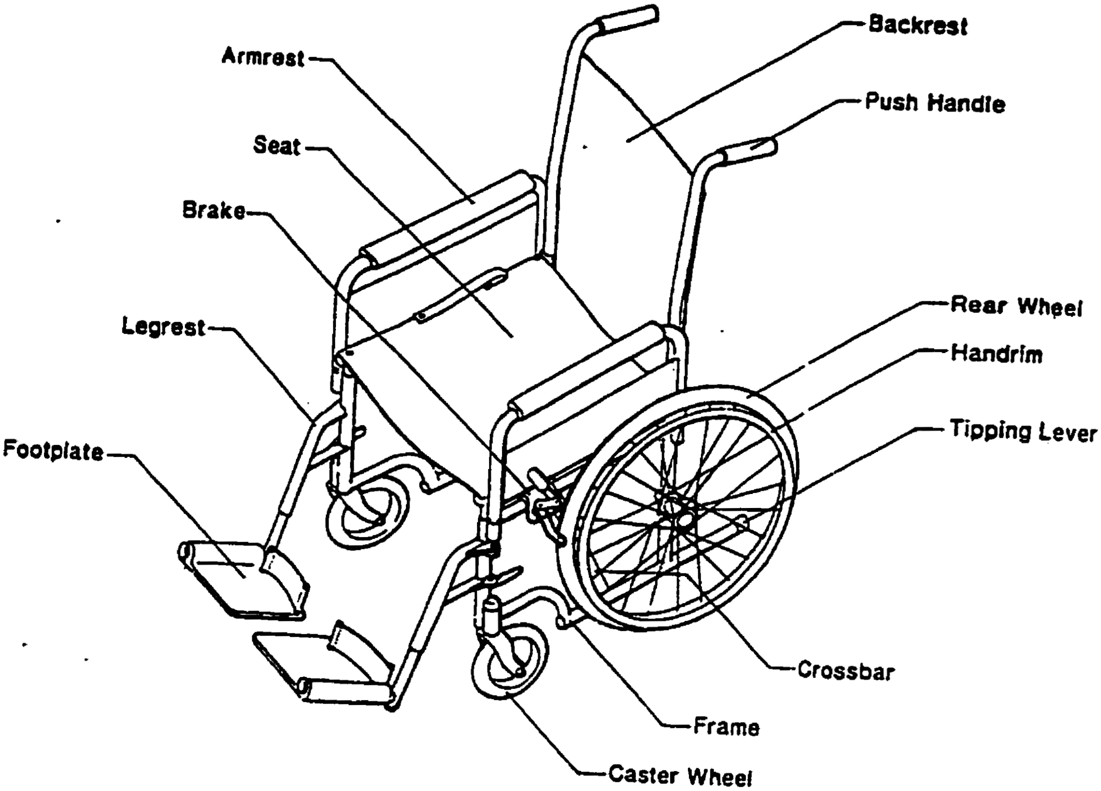


Figure 1: The Manual Wheelchair System

Each of the following components must be regulated to ensure it meets user requirements. The following table summarizes the major components:

Table 1: Wheelchair Components

Component	Description and Function	Key Issues
Frame	Main structure that supports the user and the overall system components	Strength, weight, durability and stability
Push handles	Grasping extremities at the upper posterior section of system for attendant assisted mobility	Mobility
Backrest	Posterior vertical section of wheelchair used to support user's posterior trunk	Support, comfort, stability
Armrests	Lateral elements that support users arms	Support, comfort
Seat	Large midsection element that supports user's buttocks and thighs	Support, comfort, stability, geometry
Front Rigging	Lower anterior extremities used for support and attachment of legrests and footrests	Strength, support, size
Footrest	Low anterior component that supports users feet	Support, strength, stability
Caster wheels	Low anterior components that are in contact with the ground that support frame and enable motion and steering of system	Stability, maneuverability, mobility
Brakes	Mid anterior components that prevent rotation of rear wheels	Reliability, safety, strength
Rear Wheels	Large lateral components that are in contact with the ground that support the system and enable the system to move	Mobility, maneuverability, stability, durability, comfort
Tipping Levers	Low posterior appendages that are used by the attendant to tip the user-wheelchair system backwards	Stability, maneuverability

Standards

Anybody prescribing, manufacturing or selling wheelchair equipment must be aware of standards. Standards are devised to bring some uniformity of understanding to the diverse points of view of the manufacturer, the researcher and the user of the product. Standards in the wheelchair industry were not formally investigated, established and refined until the late 1980's. The main organizations that determine standards are the ISO and RESNA. The ISO (International Standards Organization) is a body based in Geneva whose representation is made up of the official standards setting agency of each of the member countries. In the United States, that organization is the American National Standards Institute (ANSI) while in Canada it is the Canadian Standards Association (CSA). ANSI assigned an expert representation group that deals with the establishment of wheelchair standards. The other major standardization and testing organization of wheelchair equipment is the Rehabilitation Engineering Society of North America (RESNA). RESNA was organized to create a forum for rehabilitation professionals who deal with technology, engineering, and assistive devices. RESNA includes wheelchair designers, prescribers, manufactures, vendors, testers and users among its members.

The adequacy of standards relies on:
- *A set of valid requirements.* These stem from the unsatisfactory conditions of the user, and are determined by an evaluation of the user. They become the foundation of standards.
- *A translation of these requirements into appropriate hardware and functions.* This is the selection of materials, feasibility study and design of assistive equipment that meets users needs.
- *A reliable evaluation system.* Compliance with specifications, quality management, and comparison of new equipment with acceptable standards.

The potential benefits of having standards are (McFarland, 1981):
- Improvement in quality and reduction in cost.
- Avoidance of duplication in testing.
- Improvement in communication and problem-solving.

The Alberta Aids to Daily Living (AADL) government organization that owns and distributes equipment to care homes and the majority of other users in Alberta, strictly follows the RESNA/ISO standards for their products. They are also strict on any modification and alteration of the wheelchair: no welding, no cutting and no drilling. Any accessory or new piece of equipment must pass a RESNA test for it to be approved by the AADL. If there is no existing test for the new piece of equipment, it will not be approved by AADL. Usage of unauthorized equipment is at the user's or caretaker's own risk.

The following is a list of RESNA standardized tests and considerations for manual wheelchairs (McLaurin, 1990).

- *Static Stability*: Measurement of the tipping angle when the wheelchair is loaded with an anthropomorphic dummy. The test is repeated in the forward, backward and lateral directs.
- *Efficiency of Brakes*: The brakes must hold a wheelchair-dummy system in place under a specified incline.
- *Overall Dimensions, Mass, and Turning Space*: Specification of the space needed to operate wheelchair, the mass of a wheelchair and the space taken up by a folded and unfolded wheelchair.
- *Seating Dimensions*: 26 measurements are recorded on the dimensions of the seat, backrest, footrests and armrests.
- *Static Impact and Fatigue Strength*: A series of tests to determine structural strength of the wheelchair.
- *Test Dummies*: The dummies used for all tests must also be anthropometrically

standardized.

- *Coefficient of Friction of Test Surfaces*: Roughness of testing surfaces must also be normalized.
- *Disclosure Requirements*: Specifies the information that is required to be disclosed in the user manuals, product literature, and other documentation related to wheelchairs.
- *Burning Behavior*: Determining the ignitability characteristics of a wheelchair's upholstery.

Design Criteria

Criteria are attributes of designs that are the basis for deciding among design options. They are quantifiable characteristics that are subjectively determined by the user, caregiver, and designer. They stem from the user's needs and must be reflected in the design to some degree in order for the design to be adequate. Since criteria are subjective, some become more important than others. Studies have been conducted among wheelchair users to determine which criteria are most important for a device. In order of importance (Batavia, 1990):

1. *Effectiveness*: the extent to which the functioning of the device improves the user's living situation, as perceived by the user, including whether it enhances functional capability and independence.
2. *Affordability*: the extent to which the purchase, maintenance, and/or repair of the device causes financial difficulty or hardship to the user.
3. *Operability*: the extent to which the device is easy to operate and responds adequately to the user's operative commands or actions.
4. *Dependability*: the extent to which the device operates with repeatable/predictable levels of accuracy under all conditions of reasonable use.
5. *Portability*: the extent to which the device can readily be transported to and operated in different locations.
6. *Durability*: the extent to which the device will continue to be operable for an extended period of time.
7. *Compatibility*: the extent to which the device will interfere with other devices currently and in the future.
8. *Flexibility*: the extent to which the device is provided with available options from which the user may choose.
9. *Maintainability*: the extent to which the user (or caregiver) can easily maintain the device to keep it operable and safe, including whether it is easy to conduct all required maintenance, cleaning, and infection.
10. *Securability*: the extent to which the device can easily be kept within the physical control of the user to reduce the likelihood of the theft or vandalism.
11. *Learnability*: the extent to which the user, upon initially receiving the device, can easily learn to use it and can start using it within a reasonable period of time once assembled, including whether specialized training is required.
12. *Acceptability*: the extent to which the user is psychologically comfortable when using

the device in public (or in private), including whether the device is aesthetically attractive.

13. *Comfort*: the extent to which the device causes physical pain or discomfort to the user.
14. *Supplier Repairability*: the extent to which a local supplier or repair shop can repair the device with in a reasonable period of time, including whether replacement parts are readily available and whether the manufacturer must conduct repairs.
15. *Security*: the extent to which the device is likely to cause physical harm, including bodily injury or infection, to the user.
16. *User Repairability*: the extent to which the average user (or caregiver) can repair the device if broken, including whether special repair equipment is needed.
17. *Assembleability*: the extent to which the user (or caregiver) can easily assemble the device upon receiving it, including whether it is packaged conveniently.

Summary and Conclusions:

- All potential mobility base equipment users have needs.
- Needs must be determined by a multidisciplinary team of professionals, family and the users.
- All wheelchair equipment and accessories must be prescribed to that particular user.
- Prescription involves a thorough evaluation of the user's situation and unsatisfactory condition.
- Prescribers must be aware of wheelchair: standards, design criteria and hardware components.
- Prescribers and designers must translate the needs of the user into technological reality.
- Any prescribed equipment in Alberta is currently subject to the scrutiny of the AADL.

Epidemiology of Falls

Of the 30 million elderly people age 65 and over in the US and Canada, more than 25 thousand will die from and 3 million are injured by accidents each year. The majority of these accidents are attributed to falls, motor vehicle related or fire and explosion. The primary concern of this study is the fall-type accidents. Although this section of the report is meant to be a study of wheelchair related accidents among the elderly, it useful to examine first the contributing factors of falls among the elderly. Senior citizens fall more often than any other adult age group. Studies have shown (Vlahov, 1990) that more than 40% of individuals older than 65 will experience falls. Most of these will become repeat fallers. 26% of the fallers will sustain an injuries that needs to be treated (Blake, 1986). The largest single cause of injury mortality is falls, accounting for about half of the deaths due to injury in the elderly. Factors contributing to the general falls among the elderly and institutionalized people include: age, gender, primary diagnosis (stroke, amputation, trauma, other), level of activity (ambulatory, wheelchair, bed rest), mental status (alert, oriented or other), sedation or drugs taken within 12 hours of fall, time and location of fall, circumstances of fall, reaction time of individual, health and postural stability of the individual.

Postural Stability

Postural stability is the greatest cause of falling, tripping and tipping among old people. The same case applies whether the person is in a wheelchair, uses a walker or moves walks independently. Postural stability problems in seniors result from the individual's inefficiency to control and use his/her center of gravity when moving. Postural stability will be discussed in depth in the stability chapter. This section will address the potential factors that adversely affect postural stability. The majority of the factors that contribute to falls in general are similar to the ones that affect individual stability. Many of these factors are interdependent, for example medication can affect reaction time, postural stability, perception and proprioception.

Light

Light provides visual information to the individual's brain. The amount of light affects stability, reaction time, and perception. Studies show (Peszczynski, 1965) that darkness affects posture. Impaired vision and the reduction of light contribute to a person's sway. Sway is the oscillating movement everyone experiences in order to stay up right. These very small movements are controlled by the brain that tries to stabilize the body at all times. In the darkness however, these movements are noticeably greater because it is difficult for the brain to adjust to the surrounding without proper visual information. The lack of light also slows down a reaction time that could be necessary for making a spit decision prior to falling. Perception also becomes affected in darkness. In the dark there is the tendency to believe that objects are nearer or that they are moving. A person reaching for a rail may think it is much closer and falls he/she just grabs air. Also sudden changes of light give the brain mixed signals which result in loss of postural control.

This can be noticed when suddenly turning on the light in a dark room, or moving from a dim hallway to a brightly lit bathroom. A very bright light is not desirable either, as it also reduces the reaction time (Teichner, 1954). The most desirable scenario is to have:

- Well lit trouble locations such as bathroom and corridors.
- Maintain a uniform brightness throughout building.
- Keep the luminosity to a comfortable level.

Health

As health and physical fitness deteriorate with age the seriousness of the accidental injuries increases. Health affects postural stability, reaction time, recuperation and resilience. Occupational therapists, physiotherapists, and rehabilitation specialists should always be aware of a number of physical inadequacies that result from senility. These include: decreasing visual accommodation and acuity, presbyopia, lessened auditory acuity, lowered muscular strength, slowness of movement, diminished vibratory sense, slowed righting-reflex, decline in memory, weakness of attention, and sluggishness of photoreaction. All these agents contribute to accident potential. Usually a combination of illnesses and diseases will have negative effect on fall probability. More than 60% of people that fell had 3 or more diseases.

Environment - Location

The location of accidents is very significant. Accidents can happen anywhere and at any time but the areas with highest fall rates are the bathroom and bedside. One study (Anon, 1960) found that nearly one third of the accidents involved an activity associated with going to the bathroom. Other environmental hazards include: worn carpets, loose rugs and wiring, rickety chairs, worn furniture, slippery stairs, ramps and changes of surface, poor lighting, and obstructed paths to the bathroom. Due to the failure of older persons to perceive hazardous situations it becomes the concern of the staff to see to it that their living environment is as safe as possible. In addition, it has been observed that isolated elderly are at greatest risk. Elderly that are lonely or depressed should be monitored or possible immersed in a more social atmosphere.

Reaction Time

Reaction time is the time interval between a stimulus and the fastest initiation of a response. It is of course desirable for the resident to have the fastest possible reaction time not only to prevent an accident but also to minimize a potential injury at the onset of an accident. Unfortunately, with increasing age, the reaction time increases (Teichner, 1954). As mentioned before several accident-causing factors can be interrelated and reaction time is no exception. In addition to aging, poor lighting and poor visual information contribute to longer reaction time. The slowest reaction time is under darkest conditions, the next slowest is under brightness condition and the fastest reaction time is obtained under moderately bright surround. Visual and shape perception plays an important role: individuals with the best eye sight and object shape perception will have better reaction times than those that don't. Another factor that influences reaction time temporarily is a sudden movement or a sudden change in position. This could be related to hypotension. Examples of potential accidents are when residents try to get up from a chair or bed too fast. This applies to wheelchair users that try to transfer to a different position associated with a toilet, walker, or bed. More importantly for wheelchair users, studies have determined that the reaction time slows down when a body is set in motion and when there is a change in direction. As far as reaction times are concerned, the best environment for wheelchair users is one that does not allow sudden changes in velocity and direction. This includes minimizing ramps, corners, obstacles and rapid changes in surface (i.e. carpet to floor to concrete).

Time and Date

Although no direct correlation has been firmly established between accidents and dates of the month, there is a strong relationship between frequency of accidents and the time of the day. The highest probability of an accident occurring would be during the morning between 6 a.m. to 10 a.m. Activity is maximal during these hours. This when residents wake up, get up, go to the bathroom, dress, get medications and their first meal of the day. Waking up and getting up requires a change in position, sudden movement and an exposure to brighter light. This results in disorientation, a slower reaction time and postural instability. Going to the bathroom and lounge, the resident may be exposed to changes of light, surface texture and other obstacles. This is the most volatile part of the day for accidents and staff must be operating on their highest level. During periods when staffing is highest, fewer accidents occur per hour.

Drugs/Alcohol

Drugs, alcohol, medication and sedatives can all have adverse effects on the elderly. They affect reaction time, postural stability, perception and judgement. It has been found that the majority of drug influenced falls occur when the individual was taking a combination of 3 or more medications.

Mental Status

It may seem counterintuitive but alert individuals are at a higher fall risk than the confused. A study a New York Nursing Home (Kalchthaler, 1978) revealed that almost 50% of all falls occurred among the alert elderly. The reason for this is that alert individuals are more active and are risk takers. This is not to say that the confused and semi-confused people are not at risk. They make up the other 50% of the fallers. It can be inferred that any institutionalized elder of any mental status is susceptible of falling.

Wheelchair Accidents

There are 1,411,000 users in the United States, 500,000 in Britain and approximately

200,000 in Canada. About 60% of these people will experience a wheelchair accident every year, 3.4% will have an accident serious enough to seek medical attention, and .1% of these will result in death. In some old age institutions there are more falls among wheelchair users than those that walk freely or with the aid of a cane or walker. The number of serious injuries due to wheelchair accident is steadily rising every year as can be seen in Figure 2. These statistics and projecting are based on the information gathered from US medical and consumer safety databases (Ummat, 1994). There is a growing average of 36,559 serious accidents per year in the US (52 deaths) with a statistically corresponding average of 6820 serious wheelchair accidents in Canada every year.

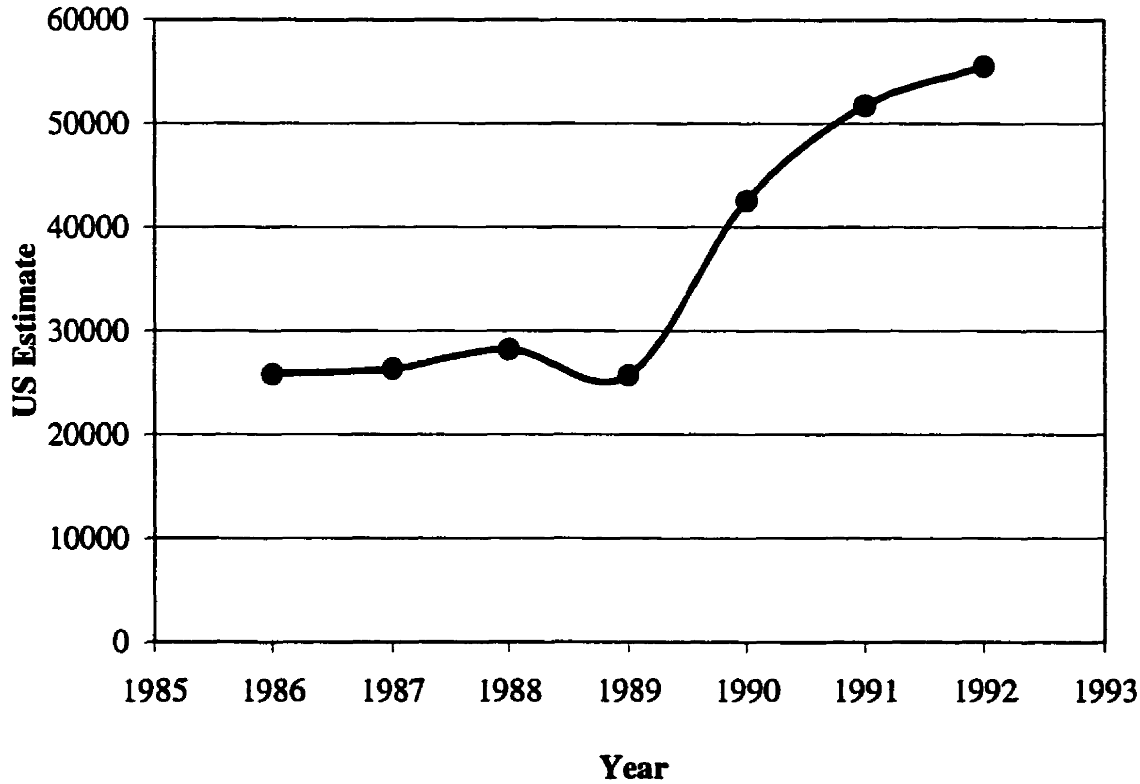


Figure 2: Yearly Serious Wheelchair Accidents

It is also important to consider the age distribution of these accidents. Figure 3 shows that senior citizens have the highest probability of suffering a serious accident. This alarming statistic indicates that the needs of wheelchair mobile seniors must be considered.

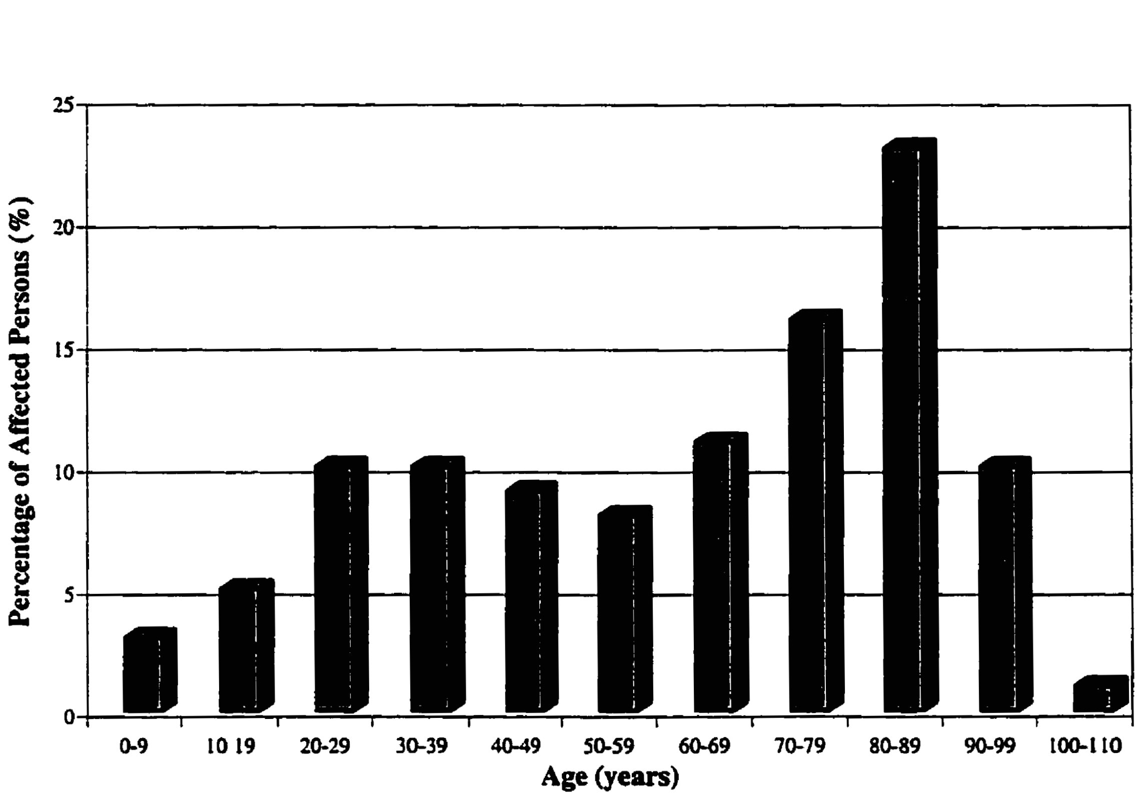


Figure 3: Age Distribution of Accidents

The average for people having serious accidents is 60.6. The majority of accidents are concentrated in the 80 to 89 years old group. Women are more susceptible to accidents than men. 62.5% of the victims were women. Another study of wheelchair related deaths over 15 years, in Figure 4, shows that the majority of deaths occur in the senior population. Again the 81to 90 age group reflected the most deaths, 38.6% of total deaths. Again women died more frequently then men, 57.3% of total population.

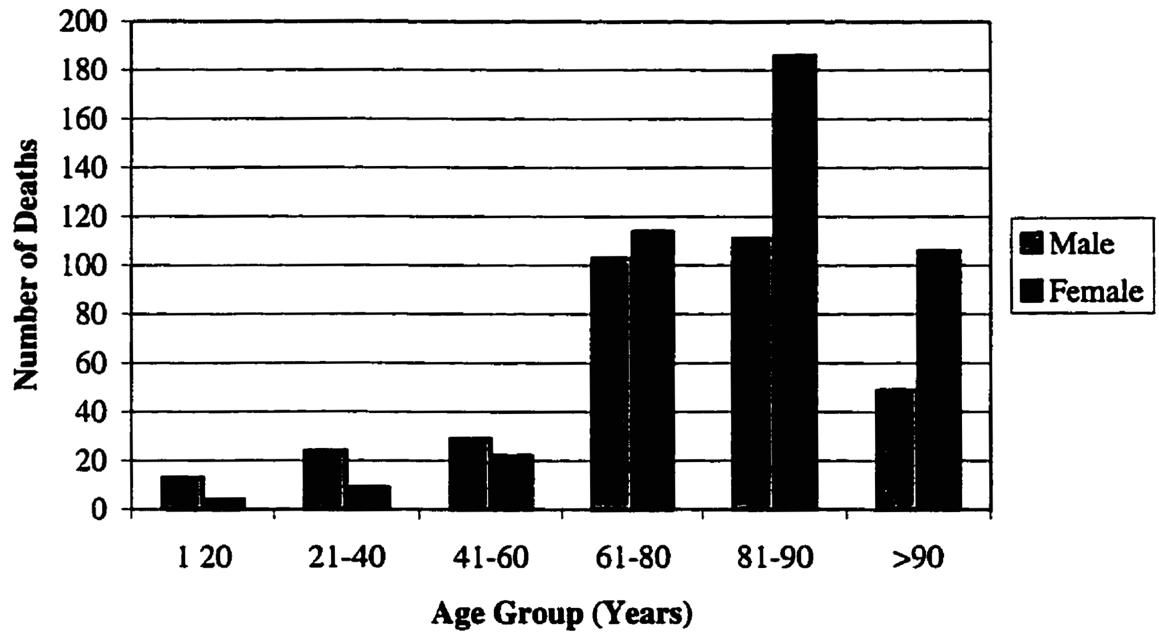


Figure 4: Age Distribution of Wheelchair Fatalities over 15 Years

A very alarming statistic is the environmental location of the death accidents. As can be seen in Figure 5, the vast majority of the accidents occur in an institution. In this case an institution refers to a care home and not hospital. This statistic warrants an investigation into the environment and policy of existing care homes.

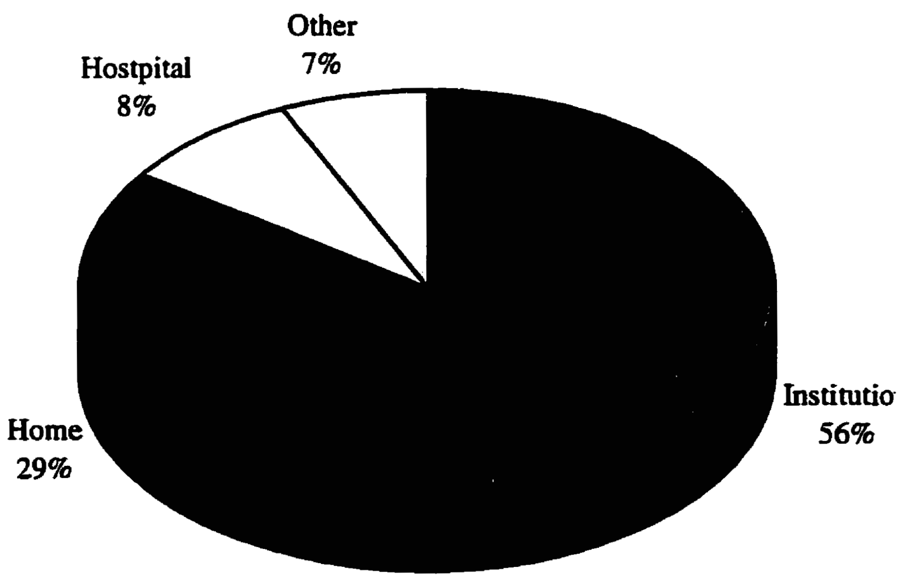


Figure 5: Location of Fatalities

Since all the accidents studied here are of a serious nature, meaning the need for medical attention, it is worth noting the type of injuries sustained and their location on the body of user. Figure 6 depicts common injuries during nonfatal accidents. The most common types of injuries are bruises followed by cuts and fractures.

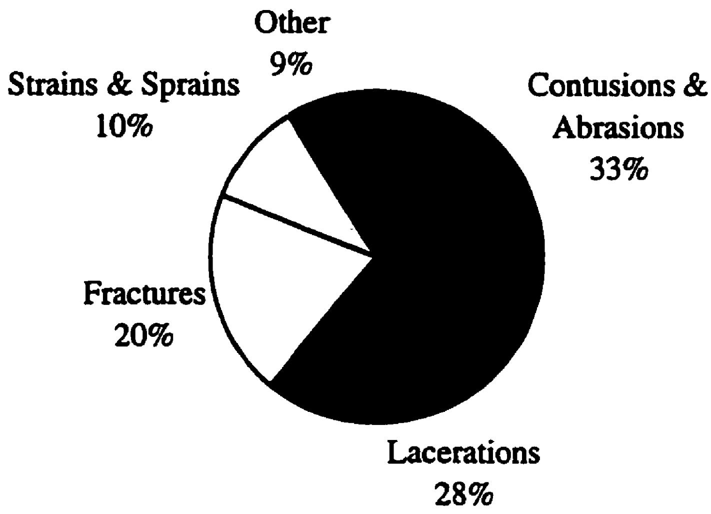


Figure 6: Types of Injuries Sustained in Wheelchair Accidents

The location of these injuries on the user's body is shown in Figure 7. The facial and head area is in greatest danger. Also due to their physiological frailty, the consequences per event increase with age.

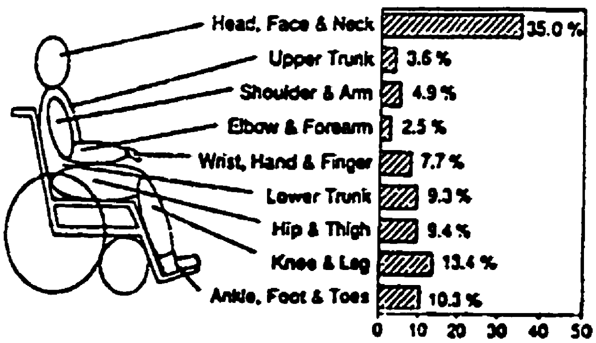


Figure 7: Body Parts Affected in Wheelchair Accidents

Figure 8 shows the body areas affected during fatal accidents. The sum of these percentages is greater than 100% because in several cases more than one system is affected. Multiple system malfunctions are typical of deaths in the senior population. Death in these accidents was not necessarily instantaneous. Many accidents affect vital systems that deteriorate and lead to death. After deaths caused by skeletal damage, the next vital area is the respiratory system. The most common respiratory system associated death is due to infection and pneumonia (25.6%). Nervous system injuries leading to death are the third most common fatal cause. The greatest nervous system injury is a subdural hemorrhage (10.8%). The fourth fatally affected system injury is the cardiovascular system. The most common cardiovascular system injury causing death is cardiopulmonary arrest, 11.4% of all accidental deaths.

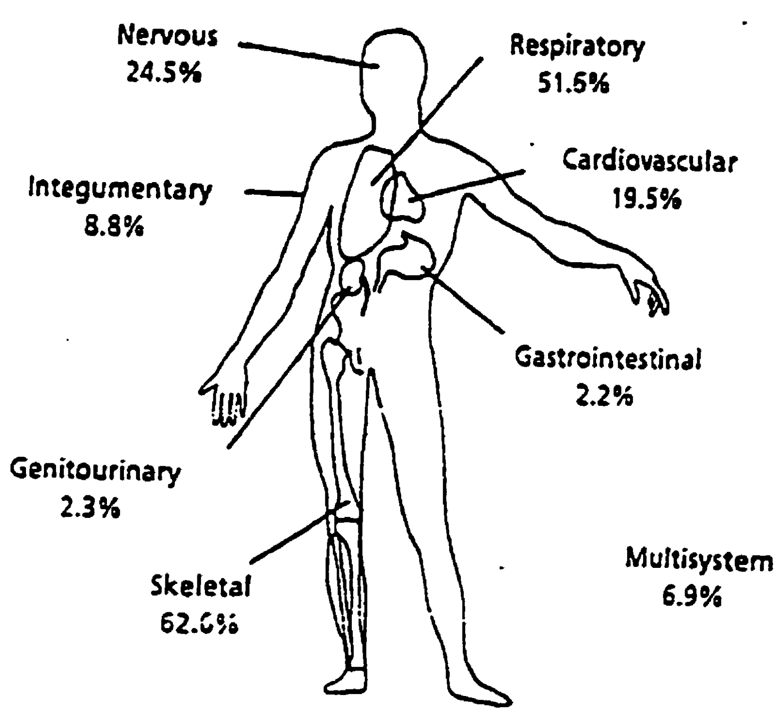


Figure 8: Systems Affected in Wheelchair Fatalities

Another aspect of wheelchair accidents to consider is the nature of these accidents. Figures 9 and 10 show the natures of fatal and nonfatal wheelchair accidents. The wheelchair is involved in almost any conceivable type of disaster: slipping, tipping, running over others, and entrapping fingers.

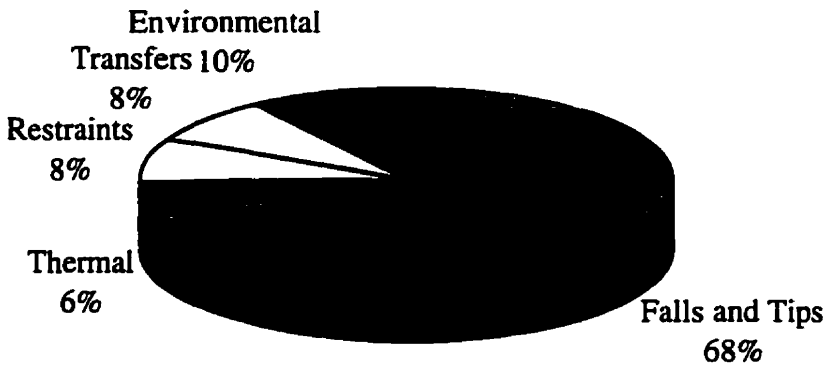


Figure 9: Nature of Fatal Wheelchair Accidents

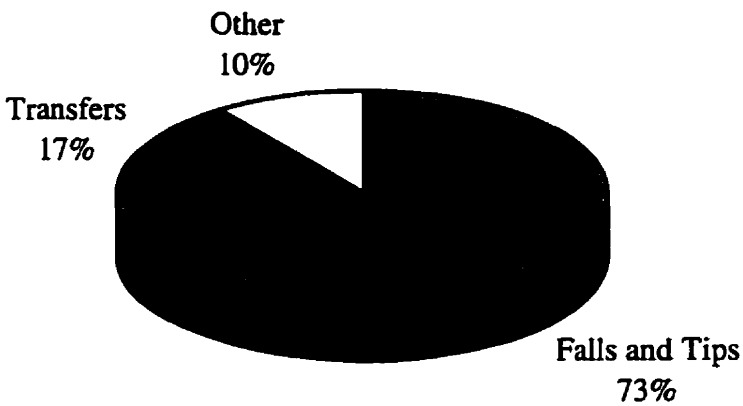


Figure 10: Nature of Nonfatal Wheelchair Accidents

It can be seen that tips and falls are the most common types of accidents. Studies have shown placed the figures anywhere between 57% to 77% of all wheelchair accidents are tip/fall related. Tips and falls are overwhelmingly the most significant cause of death.

A study conducted by Kirby (1995) shows that one of the greatest causes of wheelchair fall/tip accidents can be attributed to engineering factors is shown in Figure 11. Engineering factors primarily related to the mechanical design of the frame. This also includes strength, balance, and reliability of all components.

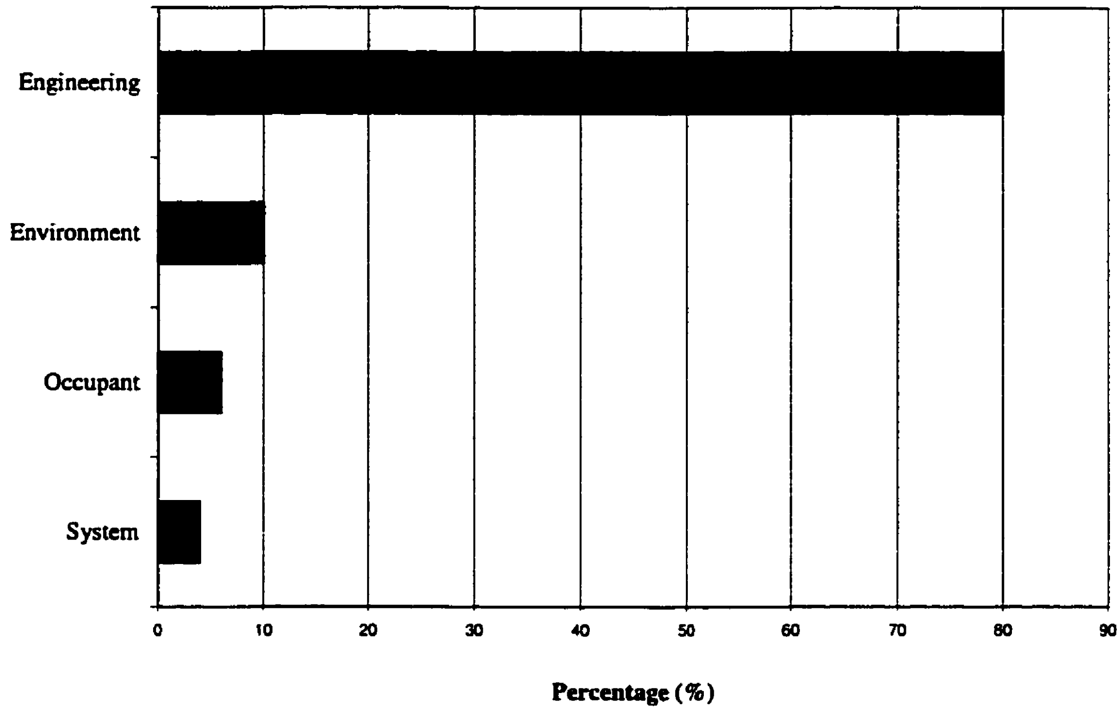


Figure 11: Causative Factors in Wheelchair Tips/Falls

Environmental factors were a distant second. These causative factors include: doors, walls, driveways, sidewalks, changes in surface, curbs, stairs, and primarily ramps and inclines. Occupant and system errors contributed the least to tipping and falling.

Lap Belts

The use of the lap belts and straps to prevent the user from falling out the wheelchair was a popular 'safety' method up until 15 years ago. This was especially used for those users that were agitators and had poor postural balance. Recent studies (Axelson 1995) have shown adverse effects of using lap belts. Not only do lap belts restrict the motions of the occupant, they can be very dangerous if improperly applied and unmonitored. Accidents happen as a result of misapplication and misuse of wheelchair lap belts. One hospital patient was found dead, half out of the wheelchair with the belt up around the throat. Anyone that is strapped into his or her wheelchair must be monitored at all times.

Accidents at the Bethany Care Center

Information gathered on wheelchair accidents at the BCC came from two sources: interviews with the staff and incident reports. From the interviews and observations the following information was collected:

- Accidents happen during any type of transfer or reaching.
- Users and especially agitators can type any mobility base.
- There are accidents related to tipping than to braking.
- Transfer guidelines are not always practiced by staff.
- There are no current solutions for users that tip their wheelchairs laterally.

From the incident reports it was found:

- There are approximately 9 wheelchair accidents per month
- The majority of these accidents were tips and falls in nature.
- 20% of these accidents required medical attention.

Conclusions and Recommendations

- All accidents must be reported at the BCC.
- Emphasis should be placed on the completeness and descriptiveness of report.
- All reports should be organized and processed statistically for easy reference.
- The majority of all wheelchair accidents, within or external to the BCC, are tip-fall in nature.
- Postural stability is a major causative factor for most elderly falls
- Overall stability of the wheelchair-user system is the greatest issue wheelchair design.
- Injury prevention depends greatly on the individual's ability to use the wheelchair safely. Although the design, components and appearance of wheelchairs continue to improve, more attention should be paid to injury prevention in future design and improvements.

Stability

The predominance of falls is caused by some form of instability. This instability can be intrinsic to the person, the wheelchair, and the person-wheelchair system. Stability can be defined as keeping the center of gravity of a body over a base. The center of gravity is a point on a body or object which is the point of balance if the body is oriented in any direction. The base is the area that contacts a firm surface, that supports the body above it. So long as the center of gravity is located above the projected base area, the body is stable.

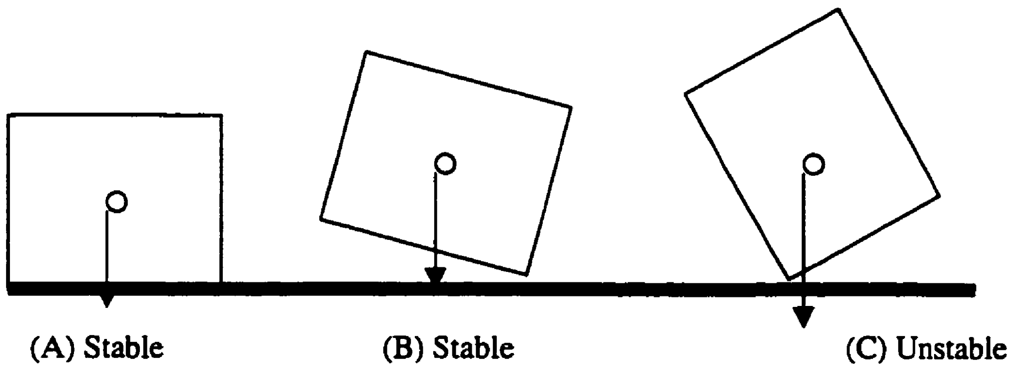


Figure 12: Stability of a Body

In Figure 12 the three objects have a center of gravity (COG) depicted by the circle. So long as the COG, is above the base (i.e. the part of the box that is in touch with the ground), the structure will be stable. The box in Figure 12 (C) will fall over on its side because the GOG has moved the right of the base, as can be seen with the projected arrow. The base of this box could be thought of as the base of a wheelchair or the feet of a standing individual. Figure 12 (C) would be the case when a wheelchair totally tips over as the GOC of the user-wheelchair system moves beyond the wheel base. The remainder of this section of the report will identify and describe the different types of stability related to wheelchair and geriatric falls.

I. Stability of the Individual

Before considering the stability of the wheelchair and wheelchair users it useful to look at the stability of seniors in general. Since the stability of the individual worsens with an increase of age, these factors become compounded when that individual is placed in a chair later on in life.

General stability

Since older people fall more than younger ones, it is appropriate to present an overview of the nature of the senior's instability. Their postural imbalance is not only associated with wheelchair user but with every daily activity a senior: sitting, rising from bed, and moving around. The physical root of the senior postural instability problem lies in their lack of effectively using their centers of gravity. Their physiological lack of control over their COG permits them to be easily influenced by various dynamic elements such as, gravity, external forces, momentum, weight, and acceleration changes. The action of walking, for example, is a combination of the economic use of the forces of gravity and inertia, and of rapidly coordinated neuromuscular activity. Younger adults have little difficulty making full use of COG in motion. They carry the body's center of gravity along a fairly smooth sinusoidal line with fewer excursions and a minimum of acceleration and deceleration during each step. The young people keep a steady gait in their walk and use momentum and coordination to move their weight with little energy expenditure. The older person exploits the work of gravity very little. Instead they have to use their own muscle power to walk. With this increased effort in walking there is a decrease of control over appendage movements and awareness of their environment. People over 75 years old, fall mainly because they are more likely to trip over trivial objects and have difficulty maintaining their balance once they start to fall.

Sway

One of the key determinants of postural imbalance of an individual is his/her degree of sway. Sway is the amount a person oscillates when standing or moving. The oscillation is a reaction to the brain controlling the position of the COG of the body. Every time the COG tries to move beyond the base of the feet, the brain instructs the body to "pull back" in the opposite direction. For non-senior adults, their musculoskeletal system is strong and contains the COG well enough for the amount of sway to be unnoticeable. But for most seniors, who become physiologically frail, have problems keeping balance because their bodies find it difficult to properly contain the COG above their feet. This is know as postural stability and can be seen in seniors that are hunched over, use a cane to walk, or tend to sway visibly. Figure 13 shows how sway is a function of age.

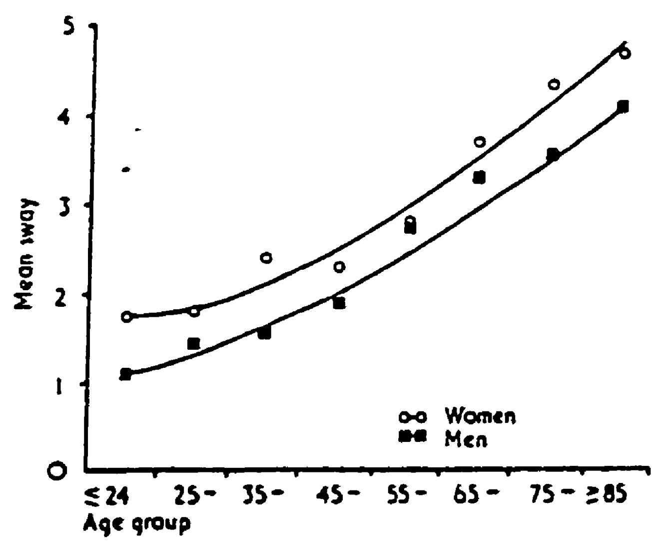


Figure 13: Amount of Postural Sway with Age

Mean sway units refer to three and a third degrees (out of 360°). This means that women, 85 years and older will sway 16.7 degrees (5 x 3.3) from their upright position. As the amount of sway increases exponentially with old age, it should become more apparent why seniors tend to fall more frequently. It is also believed that women sway more than men in any age group due to their lower body weight to muscle mass ratio (i.e. not enough muscle to support their weight).

Postural Stability in the Chair

The seated postural stability and sitting posture are derivatives of the individuals physical condition. Major diseases and conditions that affect the posture in amputations, multiple sclerosis, cerebrovascular disease, cerebral palsy, central nervous system trauma, and Parkinson's disease. The postures caused by these diseases can be classified in to two groups (Pope, 1985): those in which head and shoulders were forwards to the trunk and those in which head and shoulders were behind the trunk as shown in Figure 14.

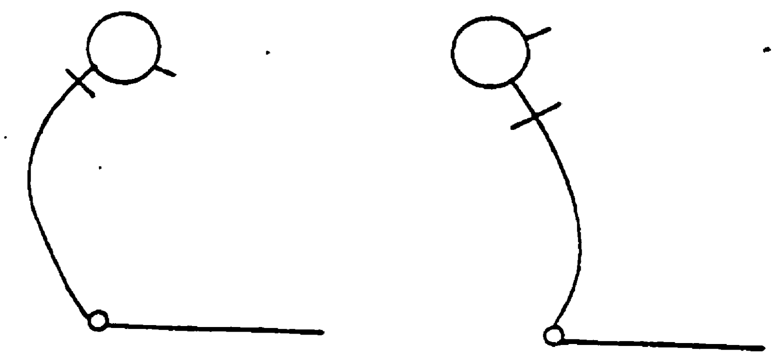


Figure 14: Seated Postures Caused by Disease.

When dealing with such postural cases, the biggest issue is seating and support. Adaptive seating support must be prescribed differently according to the individuals needs. Adaptive seating is a postural aid used to compensate for skeletal weakness or deformities which can limit an individual confined to a wheelchair (St-Georges, 1989). The seating system can be a combination of foot, head, back, thigh and lumbar supports tailored for the individual. Trunk lateral stability is a function of four sitting dimensions:

seat width, back width, back height, and back contour. Without the proper support the individual can side or fall out of the chair, his/her weight distribution is uneven causing discomfort, center of gravity is improperly located, his/her neurological impairment can worsen, and the individual is unsafe due to the overall instability.

Functional Stability in the Chair

Functional stability refers to the wheelchair user's range of motion within the chair to achieve a desired task. An important aspect of daily living which require a substantial amount of reaching to grasp objects or operate controls (Wright, 1994). Most of these tasks involve some type of reaching or leaning. This could be forward, backward or sideways reaching. The activities that involve reaching are eating, picking up a newspaper, leaning to grab a firm object to as a support during a transfer, reaching for a rail, a piece of furniture or another person. Figure 15 shows some reaching scenarios.

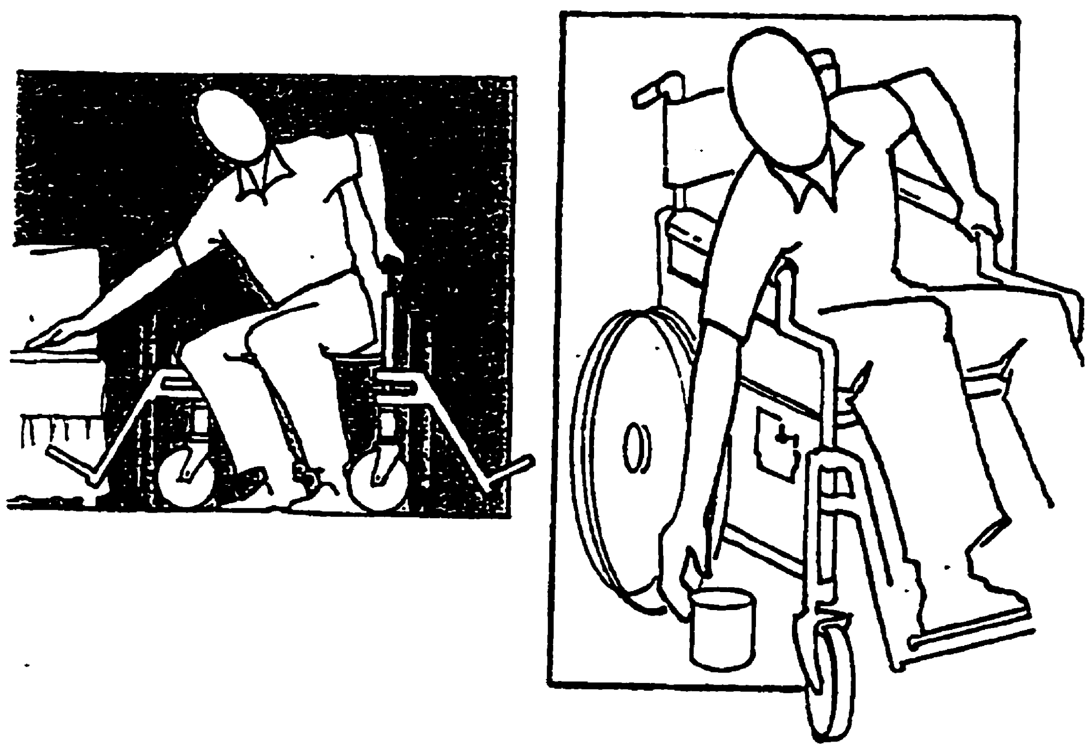


Figure 15: Reaching for Objects in a Wheelchair.

Wheelchair manufactures are very cautious and meticulous about the safety involved in reaching as described in the user's manuals. These include putting on the brakes, moving the foot rests aside, and using one and for reaching while the other holding an arm rests as shown in Figure 15. These of course are unrealistic user demands. A user wants as much freedom as possible. They should not be restricted in their upper body motions.

Ergonomic studies (Floyd, 1966) have been conducted to determine the extent of the wheelchair user's functional reach in a wheelchair. This refers to the most comfortable, safe and stable reach for a given population. Figures 16 and 17 show comfortable and maximum reach anthropomorphic data.

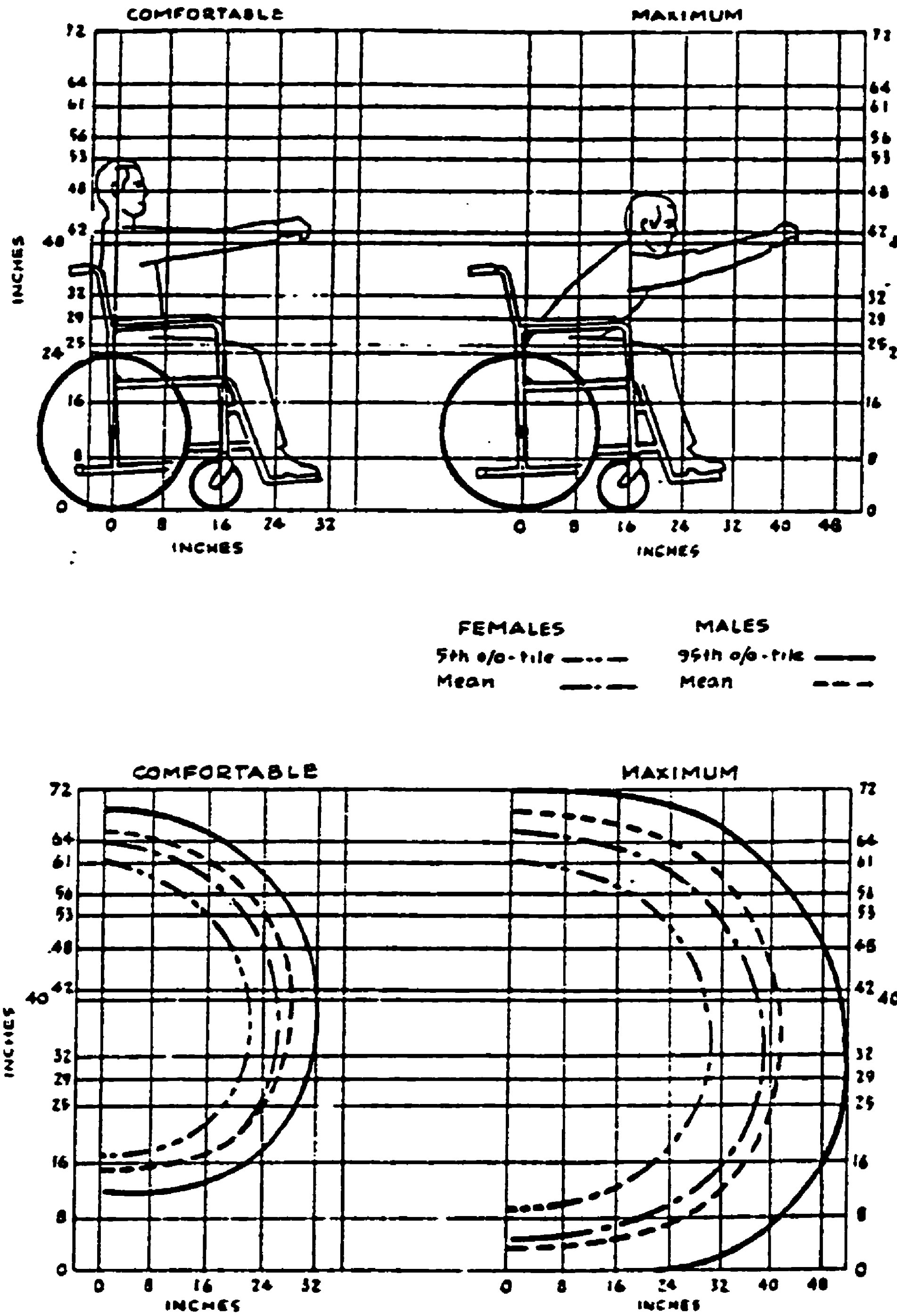


Figure 16: Comfortable and Maximum Forward Reach

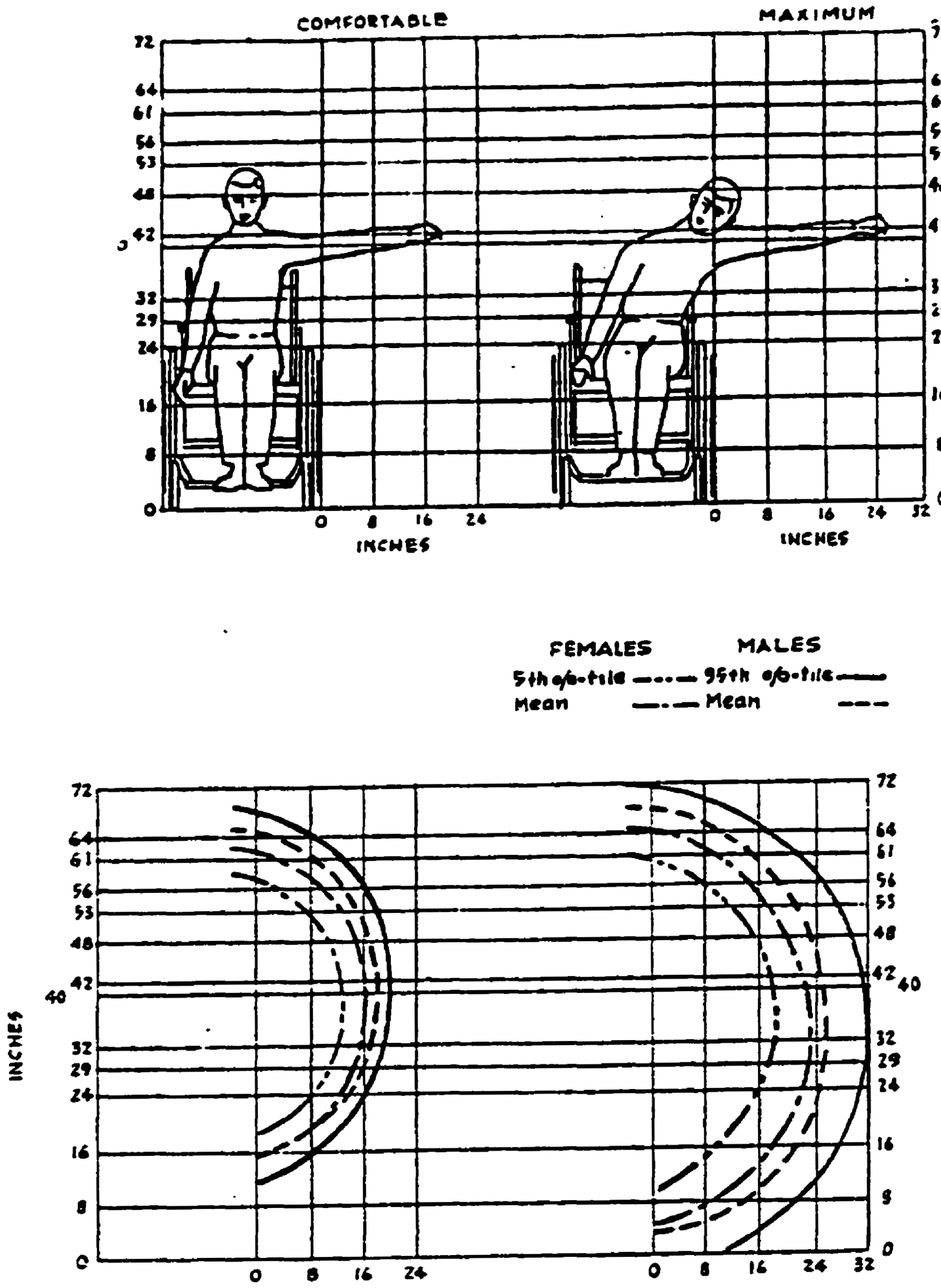


Figure 17: Comfortable and Maximum Lateral Reach for Adults

Anything beyond maximum reach can result in a hyperextention of the limb, or the user falling out of the wheelchair or the chair tipping over. If during reaching the center of gravity of the individual moves beyond the wheel base then the wheelchair will start tipping. The majority of the individual's weight is contained in the upper body, i.e. in the trunk and head. These are the two body parts that tend to extend pass the wheelchair base the wheelchair base quite easily (Duggar, 1962).

It was also found (Chari, 1986) that users can reach comfortably further is they had a proper thigh and foot support. This information is particularly useful for amputees who have a limited reach due to lack of limbs needed for support. Vlahov's study (1990) revealed that approximately 30% of the falls were due to leaning or reaching out of chairs. Thus, changing the center of gravity of wheelchairs such that reaching or leaning would not tip over the wheelchair might have some impact on reducing. Modification of the wheelchair design would probably produce a reduction in the number of falls related to reaching or leaning. 25 years ago it was very common to strap users into their seats. Many belts and harness are not only dangerous but also limit the client's reach. Curtis (1995) conducted a study on a new chest belt; it was concluded that certain chest belts stabilize individuals with T1-L1 paraplegia and improve their functional reach. It should be noted that anybody that is to be fastened into the wheelchair must be closely monitored.

II. Stability of the Chair and Person-Chair System

Since most of the stability in this category is dependent on properties of the chair, therefore the stability of the chair and person chair-system are grouped together. Figure 18 shows an example of the person-chair system.

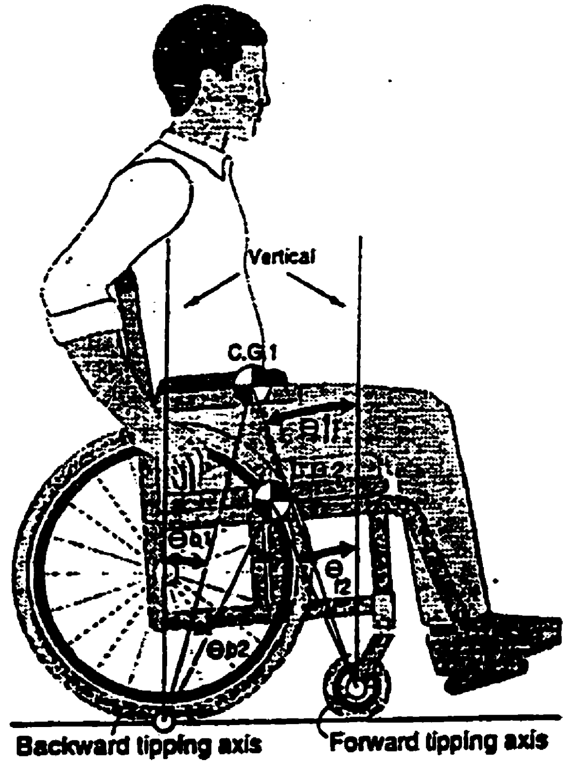


Figure 18: Side View of User-Wheelchair System

In Figure 18 the combined center of gravity of both the user and the wheelchair is called CG1. The base area of the system is defined by the pivotal points where the wheels make contact with the ground. An imaginary vertical line is drawn up from these two contact points. If the wheelchair-user system was to pivot about one of these contact points, and if the CG1 was to was to cross the vertical line, then the wheelchair would fall. This means that it is possible to tip the wheelchair forward or backwards to a certain critical point. Beyond this point, a fall will occur. It is important to not that that the location of the center of gravity (CG1, in Figure 18) is different for every wheelchair-user system. The location of the CG1 is highly dependent on the body structure, the weight distribution and particularly the height of the individual. Taller people will have a higher center of gravity, obese people will move the CG1 forward, and small people will lower the net center of gravity. Duval (1991) found that paraplegic people and many other wheelchair users have a higher center of gravity. This due to the loss of weight in the legs. It is desirable to have the center of gravity in a low position between the two pivot points at the wheel base. Therefore, since everybody has a different center of gravity, not everyone can use the same chair. The most optimal solution would be to a have a custom made chair for everyone so that the net center of gravity would be in the safest location. Unfortunately, there are only a few sizes of "standard" wheelchairs in the market that are not adequate for everyone's needs. This is why amputees and tall people tend to tip their chairs backwards, and obese short people tip forwards.

Structural Stability

Structural stability refers to the strength and balance of the wheelchair. Factors that determine structural stability are: the materials used in the frame, quality of manufacture, the geometry of the frame and the amount of mechanical maintenance applied for operation. Conventional wheelchairs are more stable in all directions than the light weight wheelchairs because the are heavier and have a lower center of gravity.

Static

The stability of a wheelchair in a motionless or almost motionless position is known as static stability. There should be no problems with stability when the wheelchair is standing on an even surface. But problems arise when the wheelchair is placed on an uneven surface, or when force is applied to a standing wheelchair. An uneven surface maybe a ramp or rough terrain outside. A force applied to a stationary wheelchair could be when the occupant is leaning to one side, or is transferring from the wheelchair, or when someone gives the wheelchair an unexpected push. Static stability is broken down further into three directions: forward, backward and side. A tip and fall can happened in any of these three under static conditions. The main wheelchair testing authorities, RESNA (Rehabilitation Engineers Society of North America) and ISO (International Standards Organization) have devised tests for wheelchair stability. In an official test, a the wheelchair is place on a ramp of 9 degrees and a 200 pound, 6 foot tall anthropomorphic dummy is place in the chair. If the chair does not tip in any direction, then the wheelchair is said to have passed the test. Most manufactures of wheelchairs and AADL have conformed to these tests and only distribute RESNA/ISO approved equipment.

Anterior

This is tipping in the forward direction. This is the most common type of tipping accident. If the center of gravity in the wheelchair-user system in Figure 18 passes over the forward tipping axis, then the system will fall forward. The position of the caster wheels influences the forward stability. If the casters point forward (unlike their position in Figure 18) then the wheel-base is extended slightly forward which makes it more difficult for the wheelchair to fall forward. If the casters are swept back (their normal position in Figure 18) then the wheelchair is less stable in the forward direction. The most common forward tipping accidents occur when the individual is transferring or leaning forward to pick up an object. During these actions, the user shifts his/her center of gravity past the forward tipping axis and may press their weight on the footrests resulting in a fall. It is important to notice that the footrests are located beyond the forward tipping axis, therefore any excess weight placed on the footrests will render the system unstable. Footrests should always be moved to the side when transferring.

Forward stability is influenced by the position of the legs. The most stable leg position would be if both legs are vertical (Kirby, 1989), this means the standard sitting position. When the legs are vertical, they are very close to the forward tipping axis (i.e. the casters). In this case the critical forward tipping angle would be 18 degrees. The least stable would be if both legs were elevated, like in a cast position. This is because the weight of the legs is further beyond the forward tipping axis. With both legs extended, the wheelchair will fall forward if it tips more than 14 degrees. For these cases a forward stabilizer is used. The forward stabilizer is an outrigger that goes forward past the casters and prevents the wheelchair from tipping forward significantly. An amputee should have no forward stability problems because he/she has no leg weigh beyond the forward tipping axis.

Posterior

Rear or backward stability is a common issue among many wheelchair users. Looking a Figure 18, a backward tip and fall will occur when the total center of gravity passes over the backward tipping axis. The amount of backward stability necessary in a wheelchair varies from age group to age group. Younger people like to "pop wheelies" and therefore require less rear stability. Older or taller people that drop back hard when getting into their wheelchairs, need the extra rear stability so that they don't tip the chair over backwards. One way of increasing the posterior stability of a wheelchair-user system would be to lower the center of gravity and at the same time to push it forward. This can be done by adjusting the seat position of the user. Altering the seat position requires an adjustable chair and moving the person forward will decrease forward stability. Lowering the seat will also compromise maneuverability. It will be more difficult to negotiate a curb or tilt the wheelchair backward to lower a client requiring a mechanical transfer. Other stabilizing or preventive methods are the common rear anti-tips. These can be used for aggressive and tall people that tend to tip their chair backwards.

Kirby (1986) found that conventional wheelchairs tend to fall backwards when a posterior tip exceeds 24-28 degrees. Lightweight wheelchairs are less stable and will fall back at around 18-20 degrees (sources vary). Also any negative camber on a wheelchair will adversely affect the posterior stability. All leg amputees or frail paraplegics will have posterior stability problems because they don't have any forward counterweight. Their body position must be moved forward, so that the center of gravity is between the two tipping axes.

Lateral

Sideways tipping represents almost a third of the static wheelchair falls, but lateral stability is the least studied. Figure 18 shows the front view of a wheelchair-user system. If the center of gravity, depicted as **Mg** in the figure, moves past the wheel base as shown, the wheelchair will fall over to its side with the occupant.

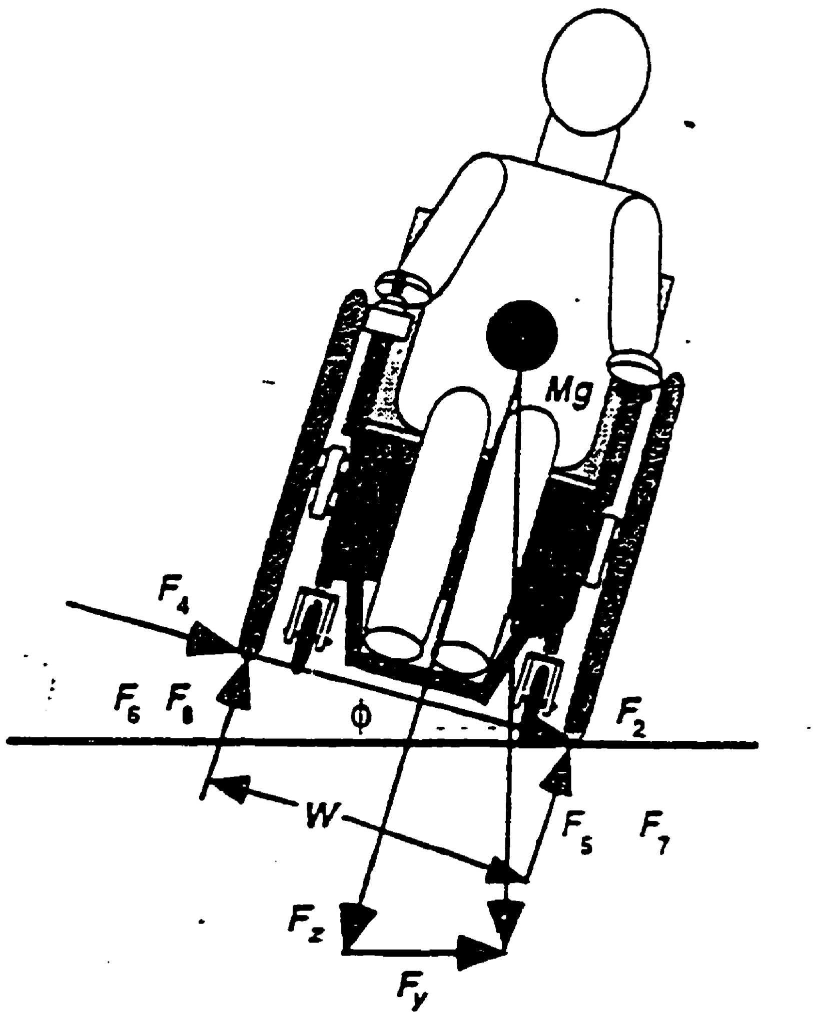


Figure 19: Front View of Wheelchair-User System.

One preventive measure for lateral tipping is to put negative camber on the two large wheels. Figure 20 shows how camber alters the configuration of the wheelchair wheels and the center of gravity.

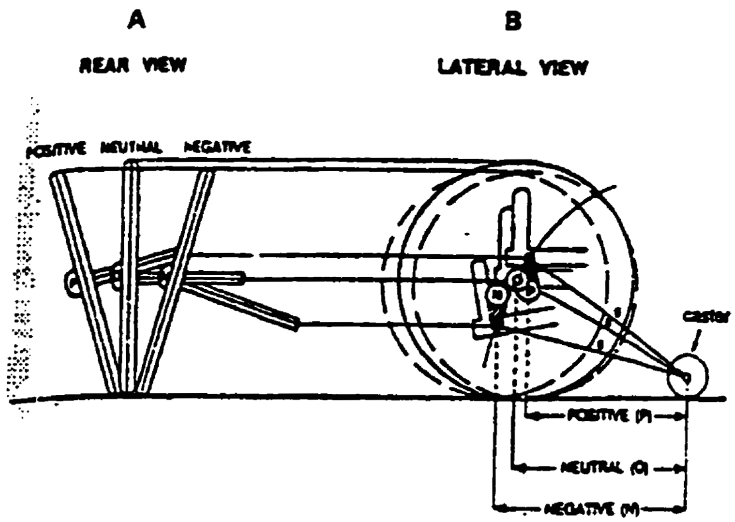


Figure 20: Wheelchair Rear Wheel Camber.

Negative camber increases the wheel base area. The greater the camber, the more difficult it would be to tip the chair sideways. The adverse effects of negative camber for elderly wheelchairs are: 1) the wheels stick out more and could impede motion in tight areas; 2) camber decreases rear stability because it moves the center of gravity backwards; 3) camber makes the wheelchair more maneuverable which reduces dynamic stability, i.e. the user has less control when moving. In order to camber the rear wheels the frame straight axle rather than the foldable model. This means getting a new wheelchair that doesn't fold. The individuals reaching and leaning has a great impact on lateral stability. Kirby (1995) found that when a person reaches to the side the wheelchair will fall over to the side once it tips more than 14 degrees. This critical angle decreases by a third is there are no armrests. Therefore the presence of arm rests is important to retard the tipping action for those people that tend to lean over the side of the wheelchair.

Dynamic

Dynamic stability refers to the case when a wheelchair is set in motion. The stability of the chair becomes a factor each time a moving wheelchair changes direction or speed. If there is a sudden change of riding surface, change in riding elevation, a sharp turn, or if the wheelchair becomes subject to an external force while moving, any of these can result in a fall. Just as in static cases, dynamic instability may result in a fall in the anterior, posterior or lateral direction. Also, there is a new form of dynamic stability; if the wheelchair wants to stay on course while moving, the element of directional stability is introduced. Dynamic stability is usually tested by setting a wheelchair and anthropomorphic dummy in motion, then placing an obstacle in the in its path. The amount of tipping a wheelchair-user system can withstand before fall in is measured. Usually dynamic stability is more sensitive than static stability and care must be stressed when an elderly person is set in motion.

As in the case of static stability, the best form of further stabilizing a chair would be to lower its center of gravity. However in the case of dynamic stability there is a trade off between stability and maneuverability. The more stable and ridged a wheelchair becomes, the less it will want to move. Maneuverability is very important in going up curves or ramps, taking corners, and the amount of effort exerted by either the user or caregiver to set the wheelchair in motion. A very low center of gravity on a heavy chair will make it difficult to move the chair about and to tip it to get out of an undesirable situation on uneven ground. Caregivers and therapists may also find an overstabilized wheelchair unacceptable when trying to transfer a client or move the chair.

Anterior

A wheelchair can easily fall forward if it hits an obstacle or comes to a sudden deceleration in a slope transition. This can happen when the wheelchair is going down a slope and hits level ground, when it comes off a curb, or when there is a change in riding surface: concrete to grass, for example. Other forward stability problems occur when the footrest is the first part of the wheelchair to make contact with the ground during slope transition. The footrest can suddenly slow the wheelchair down to such as point that the momentum carries the user forward to a face first fall. Two important features can influence forward dynamic stability: speed and caster size. If the seed is kept to a comfortable and controllable minimum there is less probability of anterior instability. Dynamic instability is always worse than static instability meaning the ideal theoretical speed should be zero. Since this is unrealistic, a slow constant speed is recommended, especially for older people. The second important element is the caster size. The larger the caster, the more difficult it will be for the wheelchair-user system's center of gravity to move past the forward tipping axis when the wheelchair hits an obstacle. Larger casters however make the wheelchair less maneuverable. Therefore if the user is not a young athlete, a 6 inch diameter caster would fulfill the anterior safety requirements.

Posterior

Since wheelchairs do not move backwards often, posterior dynamic stability is usually not a high concern. Posterior dynamic stability is only important when the wheelchair starts moving accidentally in a way that it is not supposed to. This includes going backward off of curbs or ramps uncontrollably. The large wheel in the rear is a helpful feature because large wheels do not permit the center of gravity to ready pass over their tipping axes. Posterior dynamic stability is still worse than posterior static stability because velocity introduces the forces of momentum which tend to carry a center of gravity in the initial direction even though the wheelchair slowed down or changed direction. Therefore the best solution to posterior dynamic stability concerns is to keep backward motion of a wheelchair to a minimum.

Lateral

Lateral dynamic stability is important in the following cases: taking a turn, moving on an unleveled surface, or being pushed from the side. In the dynamic case when a wheelchair tips and falls to the side, it will tend to yaw. Yawing occurs when the caster wheels point to the inside underneath the wheelchair. The tipping starts at the front, at the casters, and then the rear wheels fall to the side. So in effect the wheelchair falls to the side in a twisting manners, starting at the front and moving to the back. One remedy would be to place an anti-tipper at the front side, to isolate and prevent the yawing motion as it begins. Another solution is to put camber on the wheels. Camber makes the wheelchair very maneuverable and versatile, and prevents side falls. The major drawback of camber is that it compromises posterior stability.

Directional

Another dimension of stability related solely dynamics is directional stability. Directional stability refers to the ease in which it is possible to maintain a desired course of motion. If the wheelchair veers off the desired course, oscillates while moving, or is difficult to control by the caregiver or user, then these are examples of directional instability cases. Directional stability is largely a function of the configuration of the casters and caster design. If the casters are very small or have their vertical rotating axis in line with the horizontal rotating axis, then they will shimmy. Shimming casters vibrate rapidly back and forth when the wheelchair is in motion. Caster shimmy results in wear to the casters and prevents fluidity of motion. The location of the casters is another matter (Collins, 1988). Usually casters are in the front of the wheelchair. There are wheelchairs, known as traveler wheelchairs, where the casters are in the rear. This caster position is not desirable in terms of directional stability because the slightest lateral force on the wheelchair-user system tends to veer the wheelchair of course considerably. This can be seen if the wheelchair is moving across a slope (rather than up or down), or if someone accidentally bumps the wheelchair from the side. Therefore well designed large casters in the front of the wheelchair will keep the system directionally stable.

Summary and Recommendations

- Interventions should be aimed at teaching appropriate transfer techniques, providing adequate staff to assist with transfers, a maintenance program for wheelchairs, and individually prescribed wheelchairs.

- Wheelchair design, in terms of front castor size, anti-tip roller bars, center-of-balance adjustments, etc., should be customized according to the individual's disability/ability.

- Excessive wheelchair stability may hinder performance.

Management Issues

Management and administration of care homes and assistive devices play an important role in the lives of the senior citizens and wheelchair users. With effective management of human and technological resources and implementation of viable policies, many accidents can be prevented and the needs of residents addressed.

Need Awareness

The Canadian census indicates that there are over 3.2 million people living in permanently in this country that are 65 years old and over. This amount is steadily increasing (Pickles, 1994). Almost 50% of these seniors have some form of disability, which means any restriction or lack (resulting from impairment) of ability to perform an activity in the manner, or within the range, considered normal for a human being. Of these people 76% have a problem with mobility. Problems with mobility are by far the greatest limitation in ability in seniors. Due to the current population increase and longer life expectancy it is estimated over a third of the population will become senior citizens within the next 20 years. Care home must be prepared for the increase of seniors, an increase in their disabilities and an increase in their needs.

Care Home Administration

Addressing the needs of the residents is done through the care home's administrative structure. An effective structure or process continuously gathers information and makes short and long term decisions. Norville (1978) outlines the care home management model in figure 21.

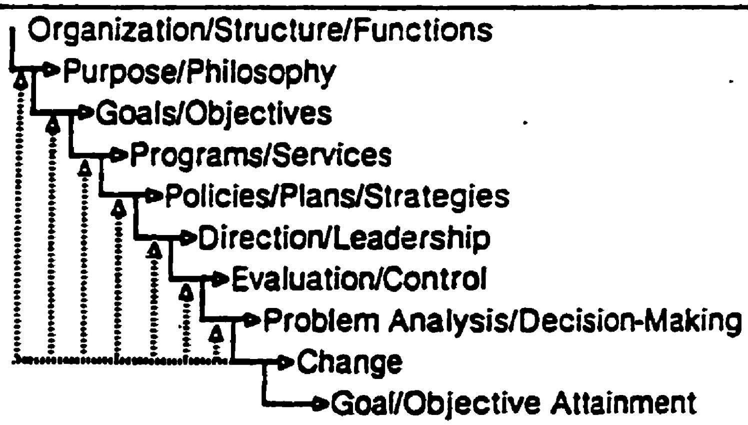


Figure 21: Management Process Model

From the this dynamic model, the principle roles of the administrators are:

- To design the organization's structure and delineate its function such that the organization serves its fundamental purpose and does so within the operating philosophy of the institution.
- Establish the goals and key objectives of the institution with the advice and assistance of key professional staff and within guidelines established by the ownership or governing body.
- Plan and offer programs and services that meet constituent needs and are feasible within the resource constraints of the organization.
- Develop plans, strategies and policy guidelines in support of goals and objectives and in relation to programs and services offered.
- Provide sound leadership and proper direction in carrying out the business of the organization.
- Establish and monitor systems/processes for evaluation and control of the organization's activities in support of programs and services.
- Identify problems (discrepancies between what is what and what should be), analyze the impact of these problems on the organization, and make sound decisions regarding corrective action.
- Carry out necessary change to ensure that the organization is achieving its goals/objectives as effectively and efficiently as possible.

Environment

The alteration of the to one which is more 'wheelchair friendly' could also help reduce the number of accidents (Dudley, 1992). Steps and curbs can be hazardous obstacles for wheelchair users. Architectural and urban planning of the care home should provide smooth and even riding surfaces, adequate space for wheelchair movement, sufficient lighting, better ramp access between levels and using principles of universal design. The principles of universal design as applied to care homebuilding include:

- *Equitable use*: the environment must be useful to people of diverse abilities.
- *Flexibility in use*: it must accommodate a wide range of abilities and preferences.
- *Simple and intuitive* use: the majority of people, regardless of experience, knowledge, concentration ability, or language skills, must be able to understand how operate within their environment.
- *Perceptible information*: the environment must communicate necessary information to the user, regardless of the user's sensory abilities.
- *Tolerance for error*: the designed environment must minimize hazards or adverse consequences of accidental or unintentional use.
- *Low physical effort*: environment can be navigated and lived in easily and comfortably with minimum physical effort.
- *Size and space for approach and use*: the environment allows for appropriate size and space for approach, reach, manipulation, and use, regardless of the user's size, posture and mobility.

It also very important that the functionality of the wheelchair within their milieu be understood and identified as it applies to wheelchair users. For example, Brooks (1994) notes that wheelchairs can play an important social role in a nursing home. The wheelchair allows the care home resident to sit wherever he or she wants and thus they could socialize independently. The wheelchair gives them more control over the environment because it gives them the ability to chose their sitting area. The wheelchair not only improves their mobility, but also their feeling of independence, sense of physical well-being, and sense of emotional well-being.

Multidisciplinary Team

The attack on senior's accident problems requires multidisciplinary approaches. Their impute provides necessary physiological, psychological and physical information for accident understanding and prevention. Figure 22 shows how the multidisciplinary team is interrelated, with occupational therapy being at the heart of the model.

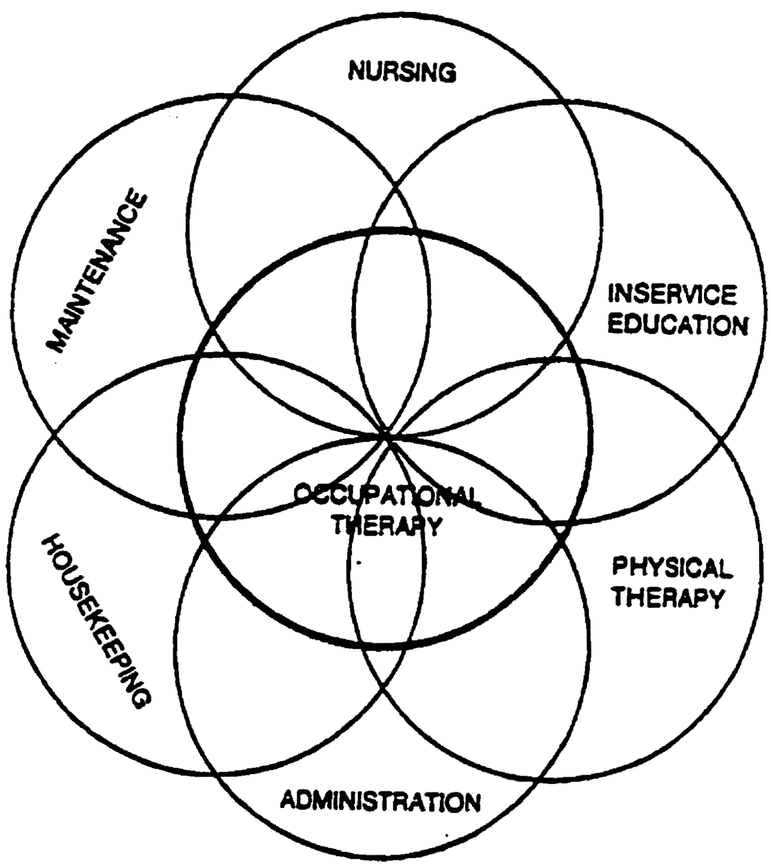


Figure 22: Multidisciplinary Team at the Care Home.

The goals of a multidisciplinary assessment of the wheelchair situation in a care home could be (Epstien, 1980):

- To assess each wheelchair user's need by identifying and cording their minimum wheelchair requirements.
- To identify and descriptively code each facility wheelchair and its location.
- To develop an information system for the data collected.
- To formulate recommendations regarding the facility's current and future wheelchair needs.
- To prepare a policy and procedure manual which would coordinate wheelchair management within the facility.

This team must also be involved in the prescription of wheelchairs and assistive devices on an ongoing basis. This is known as the continuous quality improvement (CQI) program which means that the team works with the user to learn more skills with the wheelchair, makes adjustments, and attempts to prevent injuries. CQI is a dynamic decision-making process that is illustrated in Figure 23 (Cooper, 1998).

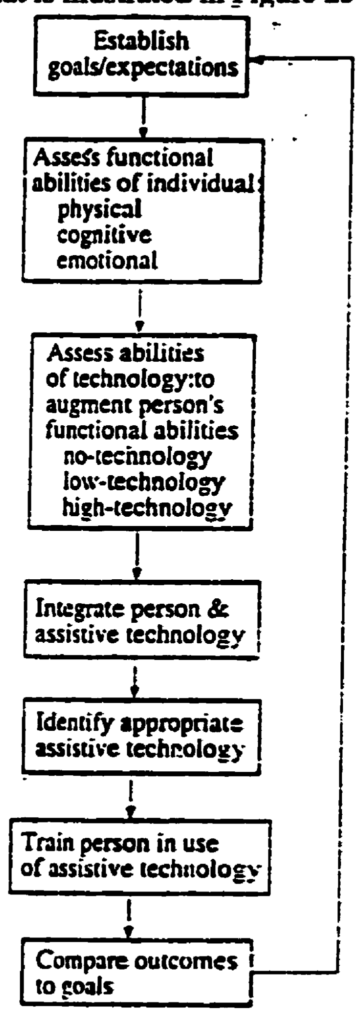


Figure 23: Continuous Quality Improvement Decision-Making Process

Through continuous relationships, the need for a new wheelchair or wheelchair accessory evolves from recognizing when the wheelchair no longer meets the individuals needs or goals.

Staffing

The staff of residential homes for the elderly carries a heavy responsibility for the care of highly selected group of vulnerable old people. While it is the salaried management staff who carry the responsibility, it is the hourly paid manual staff who actually have the power to determine what sort of life residents have, and to what extent the management's operational are implemented. The managerial goals with respect to the staff should be (Blake, 1986):

- For employees to get to know their residents better, their needs and their vulnerability.
- Better empathy with the residents.
- More job satisfaction and enhanced self-esteem.
- Better acceptance of good working practices.
- A better network of communication between workers and management.

Education

Education addresses accident prevention. It has been suggested (Lawton, 1965) that educational programs should be set up aimed at the individual citizen becoming aware of his or her problems and seeing that positive action is taken. Along with this idea, comes another recommendation, that of motivating the senior citizen to take an optimistic approach to accident prevention. Through the use of group discussion techniques in senior citizen organizations, the person over 65 can be made aware of accidental hazards, both in the care home and elsewhere, and the methods of preventing accidental injuries. Educational programs should not be limited to the elderly themselves but should include their associates and others responsible for their care. In addition to education programs early intervention programs should also be implemented. This is applied knowledge and action done to prevent wheelchair accidents in advance. This includes polices on regular maintenance, and the adaptation and modification of equipment and environment for mutually safe compatibility. Thus the preventive measures model is presented in Figure 24. The best educational programs start early in life, so that safe practices and attitudes can be carried over into the latter years.

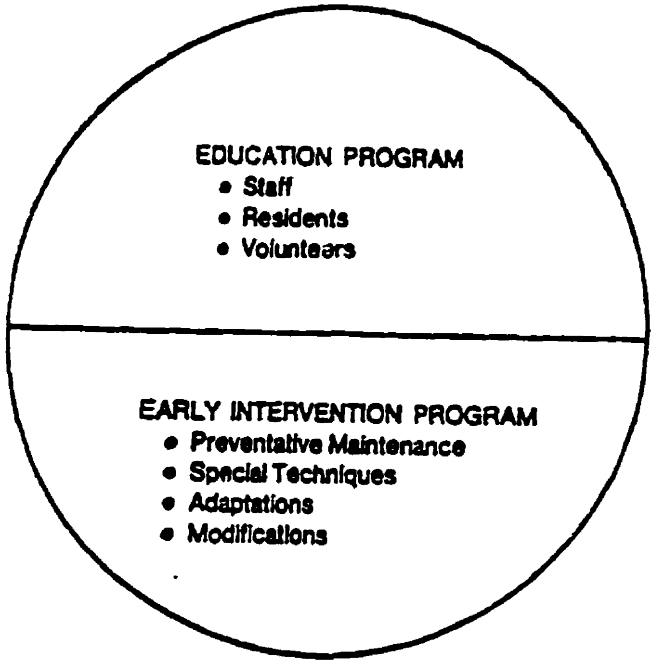


Figure 24: Preventive Measures Model

Summary and Recommendations

Wheelchair related accidents are common and many are potentially avoidable. Injuries to wheelchair occupants and attendants could be prevented by:

- Regular wheelchair maintenance.
- Identification and understanding user needs.
- Improved education for wheelchair attendants on how to erect and dismantle chairs and how to negotiate potential hazards such as curbs and steps.
- Early prevention program.
- Ensuring that the environment is made more 'wheelchair friendly'.
- Effective communication between staff, residents and management.

Mechanical Solution

Approach

The approach taken to the designing process was concurrent engineering. Concurrent engineering is a multidisciplinary approach that incorporates the ideas, needs and requirements of the users, the engineers, manufacturers and representatives of various other fields to the design process. In addition, the project was treated as a problem-solving situation that went through the natural phases of problem definition, idea generation, concept evaluation and implementation.

Need

The need is a solution-neutral statement that describes an unsatisfactory condition. Usually the user experiences the unsatisfactory condition. In this case the need statement is:

- *Certain wheelchair users at the Bethany Care Center experience lateral instability.*

Goals

Goals are statements that are responses to needs. They are usually broad but are used to set a direction for the design process. In this project the two main goals were the BCS mission statement and a more specific statement aimed at lateral stability:

1. *To improve the quality of life of the seniors and disabled residents of the BCC.*
2. *To prevent lateral tipping in wheelchairs.*

Objective

The objective is a detailed set of statements that describe the primary function of the design. This function is influenced by a set of criteria that both the designers and clients selected to be most important. The object is otherwise known as the performance specifications.

- Design a mechanism that will prevent tipping of the wheelchair in the lateral direction. The mechanism must be stable, attachable and safe.

Constraints

The constraints are imposed design attributes that must be satisfied by the solution. The designer can not change them.

- *No drilling, cutting or welding onto the wheelchair (AADL regulation).*
- *Devise must not interfere with surroundings.*

- *Must support a minimum 200 pound force (RESNA test requirement).*

Main Criteria

The criteria are quantifiable subjective attributes that are to be reflected by the design. These attributes have been identified through the problem familiarization and research phases of the process. During these phases the client requirements were recognized and translated into feasible design requirements and considerations. Criteria have been collected from the following sources: users, nurses, occupational therapists, physiotherapists, doctors, manufacturers, vendors, designers, rehabilitation engineers, disability/geriatric researchers and mangers. It must also be noted that these criteria are interdependent and must be approached holistically. The resulting criteria that are to be included in the design are:

- *Safety*: Must be safe to user and caregiver.
- *Functionality*: Must work and be effective.
- *Compatibility*: Must fit onto existing wheelchair and not interfere with surroundings.
- *Strength*: Must be strong enough to support user.
- *Manufacturability*: Must be easily built.
- *Affordability*: Must be inexpensive to make, buy and use.
- *Maintainability*: Must require little or easy maintenance.
- *Dependability*: Must work over long periods of time.
- *Learnability*: Must be easy to use.
- *Flexibility*: Must be adaptable to variety of wheelchairs.
- *Assembleability*: Must be easily assembled together and fixed to the wheelchair.
- *Acceptability*: Must be accepted by users, caregivers and administration.

Concepts

To meet the given needs, constraints and criteria various ideas were generated and considered as potential solutions. To get ideas the following sources were consulted: manufacturers, wheelchair technicians, patent searches, literature searches, engineering design and mechanisms literature. Patent searches revealed nothing. This solution would be quite original. Only Invacare is currently working on the lateral tipping problem. Also, since this was a problem of stability, the physical theory of stability had to be analyzed. All ideas were scrutinized with respect to the desired criteria and constraints. The three major concepts considered were:

- ***Variable Center of Gravity***
- ***Automatic Outriggers***
- ***Lateral Anti-Tippers***

Variable Center of Gravity

The concept behind this mechanism was to automatically alter location the center of gravity of the wheelchair in response to a tip in any direction. If, for example, the wheelchair was to start tipping forward, the mechanism would migrate the center of gravity to the posterior section in order to counteract the forward motion. This design would definitely do everything to stabilize the wheelchair. However there were limitations:

1. The wheelchair would become over-stabilized which would restrict maneuverability.
2. The mechanism would be mechatronic. This requires batteries, computer control system, sensors and actuators.
3. The mechanism would be complex and would interfere with the functionality of the wheelchair.

Due to cost, complexity, maintenance and restrictions in maneuverability, this concept was dropped.

Automatic Outriggers

In this idea, outriggers would automatically be released from the sides of a wheelchair to prevent it from tipping to the side. The device would be clamped to the side of the chair and would not be visible during normal use. When the wheelchair starts tipping to the side, the mechanism would open up to the sides like a kickstand, to prevent further tipping. The bonus of this mechanism is that even though these are outriggers, they are not permanently protruding sideways. They are compact with the wheelchair and jump out when needed. The major down falls were:

1. If the outriggers jump out, they need to be reset by caregiver.
2. If they become released when not needed, they may injure a bystander.
3. The mechanism needs a sensor and an actuator to detect tipping and to be released.
4. The mechanism operates on dynamic principles. It only works when the wheelchair is already falling and it jumps out to intercept the fall. The wheelchair-user system, while falling, generates a great force that needs to be safely contracted. The reliability of such a mechanism is questionable.

Therefore due concerns of safety, complexity and maintenance the concept was rejected.

Lateral Anti-Tippers

Lateral anti-tippers are extremities, or legs, that protrude from the sides of the wheelchair. Their primary function is to prevent a lateral tip from the onset. Whenever the user tries to reach or grabs something from the side and starts tipping the wheelchair, the device will stop the tip in its earliest stages. The most undesirable feature of the lateral anti-tippers are that they permanently stick out. This protrusion may interfere with the mobility of the wheelchair as it passes doors, goes through tight spaces or passes close objects. Based on this usability premise, the concept was originally discarded. Upon further revision, it was found that if the these anti-tipper could be made so that they can accommodate passage of the wheelchair through obstacles, then this design could prove worthy of further development. The idea that emerged that would allow the anti-tippers to pass by near objects was having the anti-tippers contain a spring-loaded hinge. In its nominal position the anti-tippers would protrude, but when they come dynamically in contact with an object they fold forward or back (depending in the initial direction of motion). Once contact between external object and the anti-tipper ceases (i.e. when the wheelchair passes the lateral obstruction in its path), the anti-tippers 'spring back' to their nominal position, ready to be used. Based on functionality and manufacturability it was decided to develop this concept.

Description of Spring Loaded Anti-Tipper Design

Please refer to the production drawings immediately following the Mechanical Solution section of this report. The anti-tipper assembly is composed of five parts: the clamp, the cantilever, the leg, the diagonal link, and the sliding hinge link. There are production drawings of all these parts individually, plus their assembly drawing and the overall assembly to the wheelchair. The anti-tipper is a bent leg that protrudes on both sides of the lower anterior section of the wheelchair. It is attached to the wheelchair in two places by clamps. There are two tubes that run along the sides of the wheelchair. The cantilever is clamped to the lower tube, the diagonal link is clamped to the upper tube. At the end of the cantilever there is a hinge that contains the spring. The other part of the spring hinge is on the leg that extends down toward the floor. The cantilever and leg are joined at the spring-loaded hinge. The diagonal link, which is clamped to the upper tube on the wheelchair, is joined to the cantilever by a sliding hinge link. The sliding hinge link allows for adjustability of the device if the space between the two wheelchair tubes varies vertically in different wheelchairs. All parts of the wheelchair can be made from aluminum bar stock for strength and lightness.

Criteria Incorporated into this Design

Design for Safety

Safety is a key issue and was the priority of the designer. In this case safety is a function of strength, and usage. The design is strong enough to support a heavyset user and to prevent tipping even after repeated attempts by the user. Since the anti-tippers are spring-loaded and easily allow passage near objects, it appears that caregiver or bystanders are not in danger to get hit hard by the anti-tipper accidentally.

Design for Functionality

One the biggest concerns of the occupational therapists was that the design must work every time. Key factors that compose functionality are safety, usability, and kinetics. Kinetics is the study of objects in motion with reference to forces. It was studied that when wheelchairs tip sideways, they tend to yaw at the front. This means that the casters are swept away from the direction of the tip and the tipping starts at the front. For this reason the anti-tippers were attached to the front of the wheelchair to eliminate the tip from the onset and not allow the wheelchair-user system to gain any further momentum. The clearance between the floor and the 'foot' of the anti-tipper is very small allowing only a minimal tip. Since the tip so small and the center of gravity of the wheelchair-user system will not pass over its base, the wheelchair will immediately tend to return to its regular upright position. A spring was selected that would allow minimum resistance while folding anti-tipper at the hinge and is strong enough to return the anti-tipper to its nominal position. Specifications and location of the spring are outlined in the production drawings.

Design for Compatibility

Since AADL regulations forbid any drilling or welding in the wheelchair frame, the device has to be clamped to the existing frame. The clamps are set for the standards 7/8" tubing found on most conventional wheelchairs. They can be easily mounted and removed by a caregiver or technician. Since the nature of the device is to allow easy access past side obstacles, therefore it will not interfere with the surroundings of the wheelchair. The spring-loaded hinge allows the anti-tipper to move both ways. There fore the wheelchair can pass obstacles forwards and backwards. The design is quite compact and does not present the appearance of wideness. The leg part or the anti-tipper could have been horizontally shorter if not for the clearance required for the caster rotation. The anti-tipper is therefore compatible with both the wheelchair and its environment.

Design for Strength

Obviously the design must be strong enough to support a heavy person. This depends on the materials used and the geometry. The parts have been made of aluminum bar stock to prevent breaks and deformation. Furthermore, the diagonal link was introduced to cantilever. The diagonal link, which is attached to the cantilever by the sliding hinge link, forms a triangle with the cantilever. The triangle, or truss, is the most stable structure. This geometry further introduces strength and stability.

Design for Manufacturability

Manufacturing was considered during all phases of the development of the design. Manufacturability takes into account the following factors:

- *Labor*: Due to the simplicity of the design, any metal shop technician can manufacture the product. Its production does not require more than one person to perform the task.
- *Cost*: Cost is based on the price of materials and the time required for production and assembly. No exotic materials were used which results in a lower price. Given the proper fully dimensioned production drawings, an anti-tipper can be manufactured and assembled in less than a day by a technician.
- *Material*: The materials used are primarily aluminum bar stock. Aluminum is strong enough to support the wheelchair-user structure. This material is low cost is ready available in all materials stores. Aluminum is easy to work with in terms of manufacturing processes. Its brittle qualities make it the product rigid. It is also very light.
- *Availability*: The tools, labor and materials for production are relatively easy to find. The design can be constructed on site in a majority of metal shops. No specialized labor or exotic tools are required to complete the product. The springs can be ordered in a day and kept in stock.
- *Process*: The manufacturing processes used in the production of the stand all material removal processes. This includes cutting, drilling and milling. All these machines can be found in a standard machine shop.

- *Assembly*: Ease of assembly is based on number of parts, the time it takes to assemble them, and the tools and fastening components required for assembly. The system has less than 5 major parts. No heavy tools are required to assemble them. The fastening devices are pins and bolts. It can be put together by a technician in less than half an hour.

Design for Affordability
This is clearly the cheapest solution from the concepts considered. Since this a simple, purely mechanical solution that requires inexpensive materials and labor, it is therefore the most affordable.

Design for Maintainability
This device can be easily maintained most of the time it will not be used. It will only be used for the brief moments of getting past an obstacle or preventing a tip. Therefore will not get worn and doesn't need replacement. It contains no electronic components that need to have a power supply and periodic calibration. Any loose bolts can be easily tightened by a caregiver and anticipated repairs are minimal.

Design for Dependability
Due to its structural stability, wear resistance and mishap prevention, the design appears to be functional whenever called upon. This means user or caregiver need not be concerned about its functionality because it is always ready to prevent an accidental tip.

Design for Learnability
From the user standpoint the design is very easy to use. In fact there is nothing to learn for the user. The user only needs to be comfortable with the idea that he/she has anti-tippers. The caregiver and technicians have to install and adjust the device that is self-explanatory.

Design for Flexibility
The design is adaptable to variety of wheelchairs. The sliding hinge link and the diagonal link allow adjustability to different wheelchair frames. Also the design is meant to be modular. This means that the shape of the design is the same but certain parts can be manufactured longer or shorter depending on the wheelchair. Thus far it has been observed that the design can fit on most conventional wheelchairs.

Design for Assembleability
The design can be easily assembled together and fixed to the wheelchair. The part count has been kept to a minimum and therefore its simplicity makes assembly and adjustment self-explanatory. Also there are no left/right parts, everything assembled one way on both sides of the wheelchair.

Design for Acceptability
It is anticipated that the design will be accepted by users, caregivers and administration. The staff may not necessarily be comfortable with the idea of side outriggers but upon

closer inspection the anti-tippers are not that visually imposing or ugly. It is a compact non-obstructive design that the user and caregiver will get used to easily. It should also be noted that the biggest concern of the therapist was door clearance. A standard doorway is about 36 inches wide. The width of the wheelchair with the anti-tippers is 34 inches, so there are cases where the spring hinge won't even be necessary to clear a narrower space.

Limitations

As with any design, there are benefits and shortcomings. This design is no exception however the drawbacks are minimal and can be accommodated:

- *Testability*: There are no standard tests for such as device. Furthermore, most tests are static and include a lifeless anthropomorphic dummy. This device is not meant to be used statically, it is quasi-dynamic and is influenced by a complex system of irregular forces. This is when a user leans over the wheelchair and tries to pull him/herself using a handrail of piece of furniture. It seems very difficult to devise a standard test that would examine the anti-tippers full functionality. AADL will not endorse any product that has not been tested using RESNA/ISO standards.
- *Foolproofness*: Nothing is foolproof. If someone is adamant about tipping their chair, they will probably do it. However, it will be difficult for the user and it will give a caregiver enough time to react to the situation.

Recommendations

This device can be implemented to almost any user of conventional wheelchair. Realistically the occupational therapist should identify any body that has a history of falling to the side or any potential fallers. Like any assistive device it should be prescribed and the user's problem must be carefully evaluated. The anti-tipper may not be the best solution for those residents who are agitators and have a high degree of cognitive dementia. Cognitive dementia refers to a lack of understanding of the consequences of the user's behavior. Thus if someone is violent and doesn't realize that they can easily fall, then these anti-tippers will only retard their efforts but not necessarily prevent the tip.

The device is suitable for:

- *Regular and potential fallers.*
- *Those with a higher center of gravity: tall people, leg amputees, and users requiring elevated legs.*
- *Anyone with poor eye sight and poor depth perception.*
- *Anyone with poor postural stability while in the wheelchair.*
- *Residents with spatial dementia or disorientation.*

The device will not be completely suitable for:

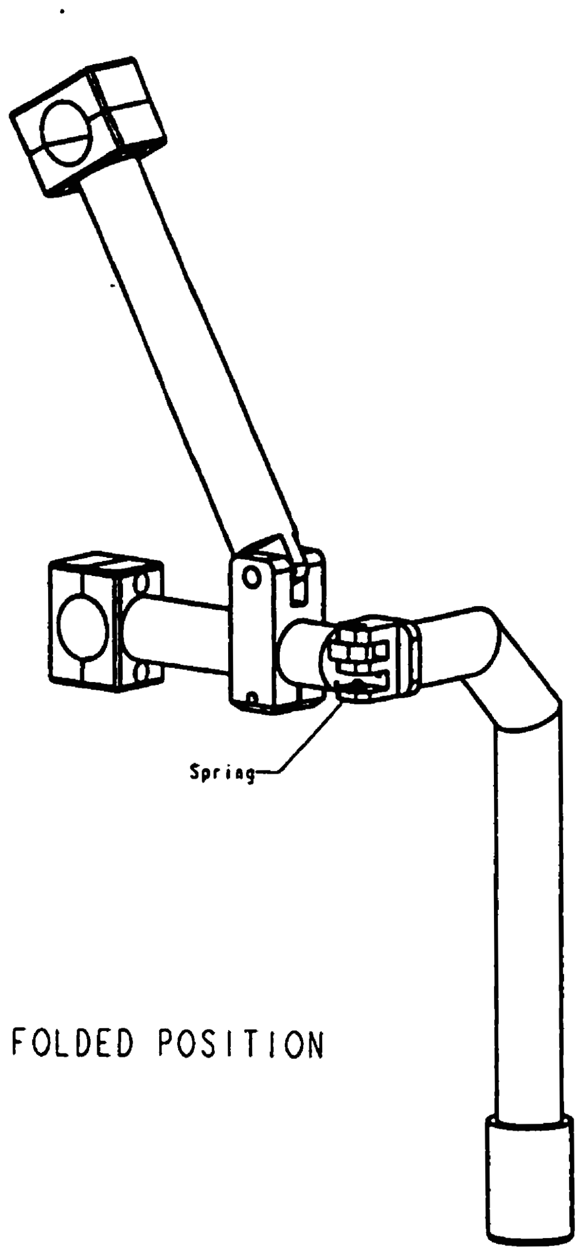
- *Agitators with high degrees of cognitive dementia.*

Future

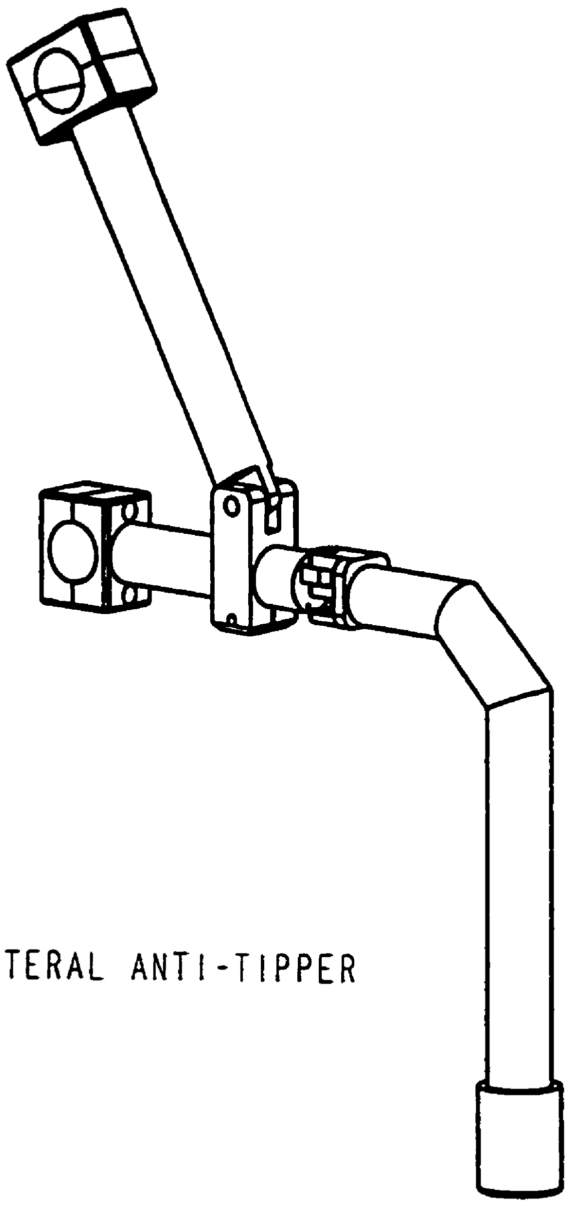
The future of this project lies in the decision of the BCS management. The current design is functional and performs what it was supposed to do. However since it is a working model, it can be improved. Certain design “flaws” may be discovered upon manufacturing and testing of the product. These can be addressed in its next stage of evolution. If BCS decides to pursue this project, it is not known how many units it wants. It is unknown who will produce them and where else will they go. This will potentially open a new chapter to this design that will include mass manufacturing considerations, legal issues, patents, industrial standards, and major marketing issues. For now, the designer kept his end of the agreement.

Summary and Conclusions

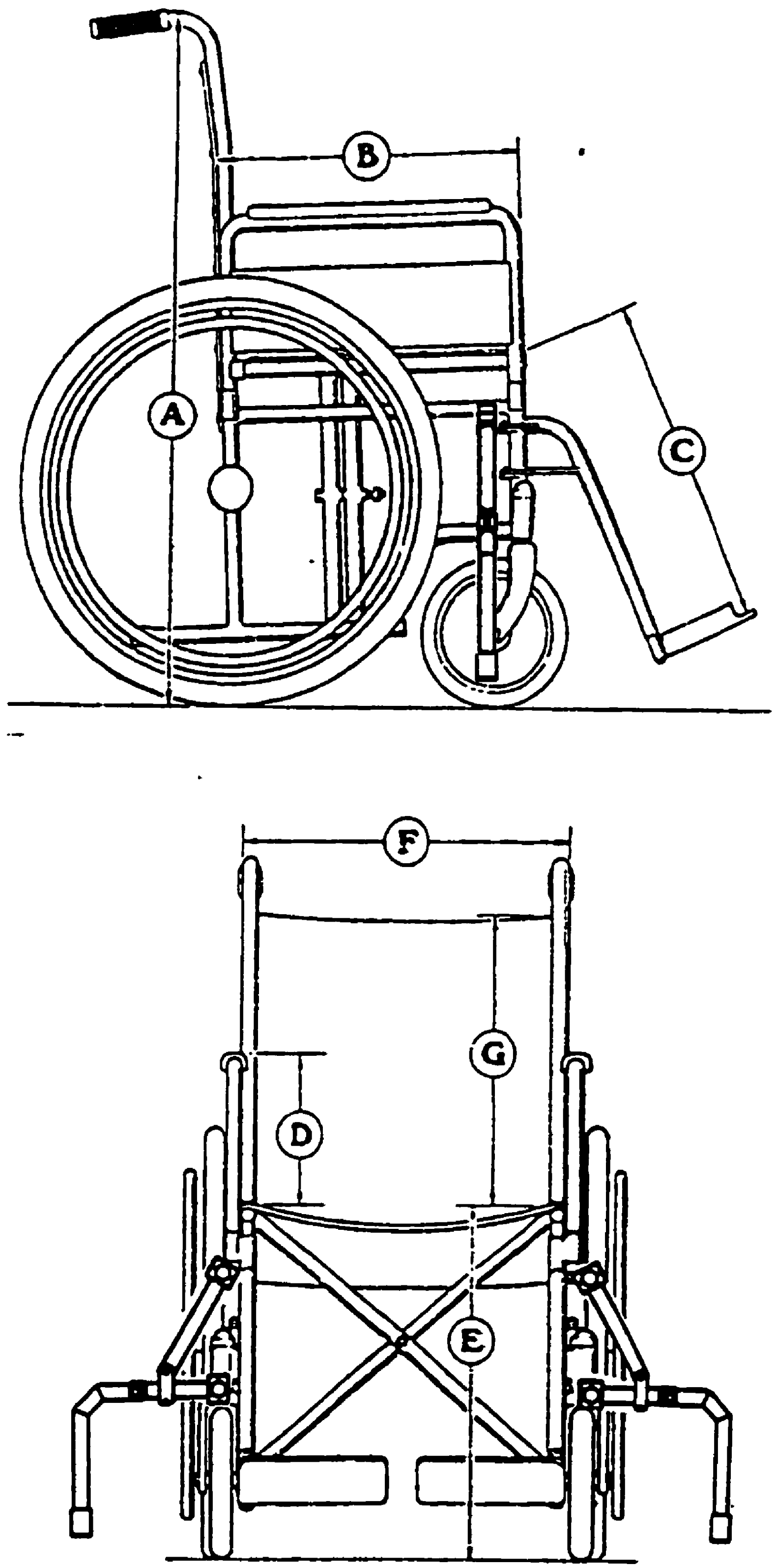
- The lateral stability needs of the users were recognized.
- The objectives, goals, criteria and constraints were identified and implemented in concepts.
- Concepts were evaluated with respect to the criteria.
- The Spring-Loaded Anti-Tipper design was chosen.
- The design prevents users from tipping their wheelchair and permits easy movement of wheelchair in its surroundings.
- The design can be implemented for anyone with postural instability, poor vision and depth perception, higher center of gravity and those that have a history of falls.
- The prototype has to be tested in a care home environment and evaluated.
- This device should only be prescribed to a resident upon a complete evaluation of their needs.



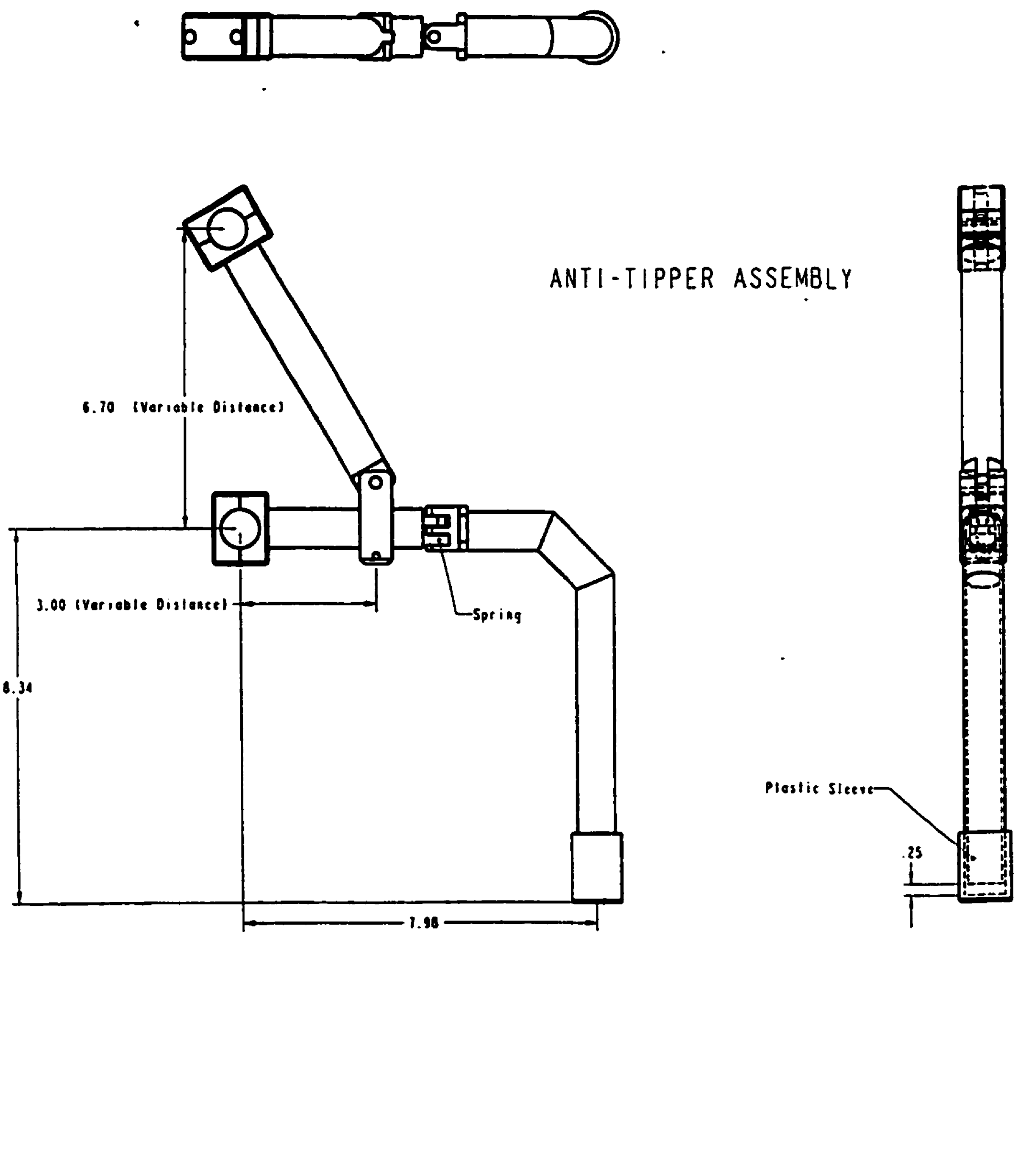
ANTI-TIPPER IN FOLDED POSITION

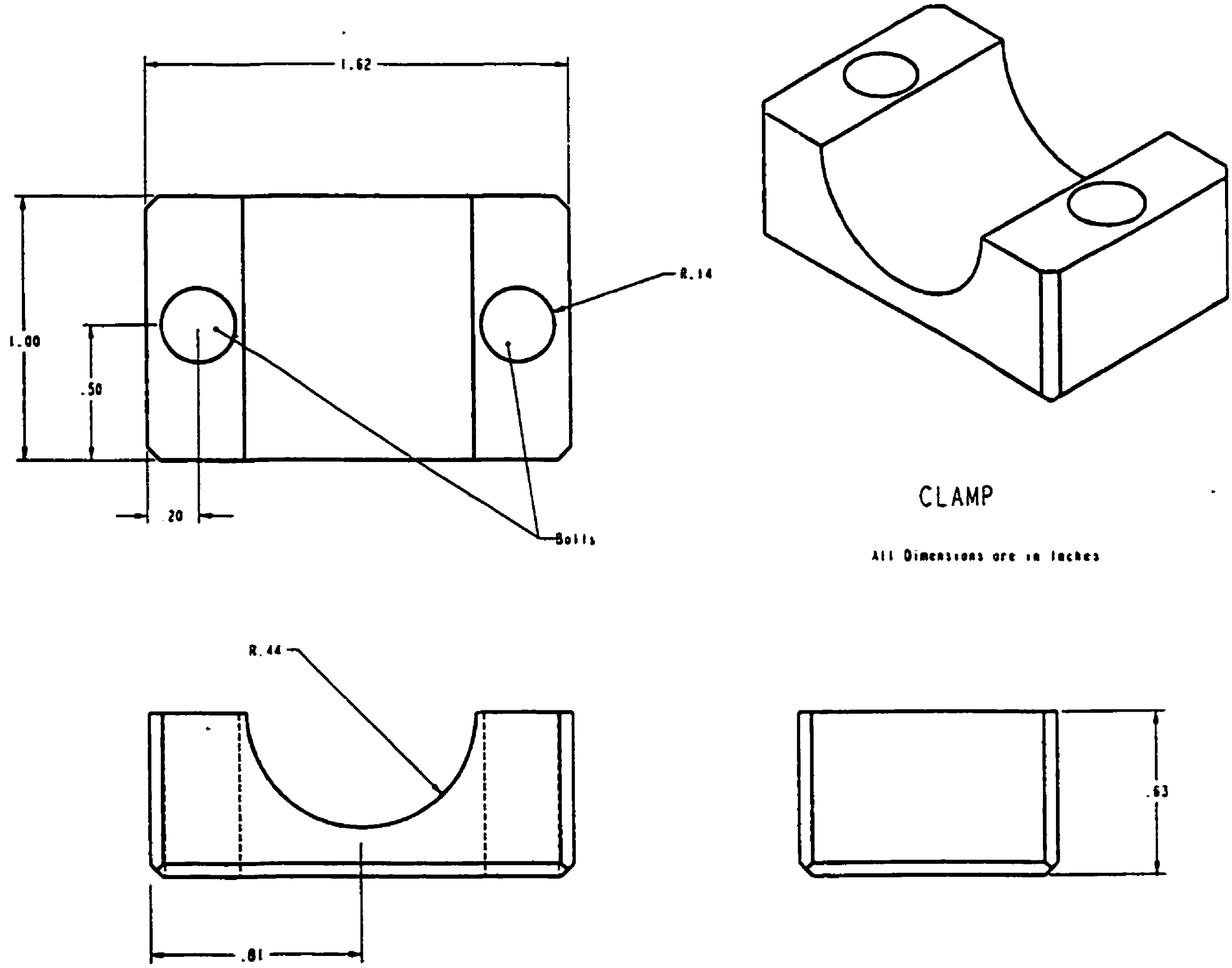


THE SPRING LOADED LATERAL ANTI-TIPPER



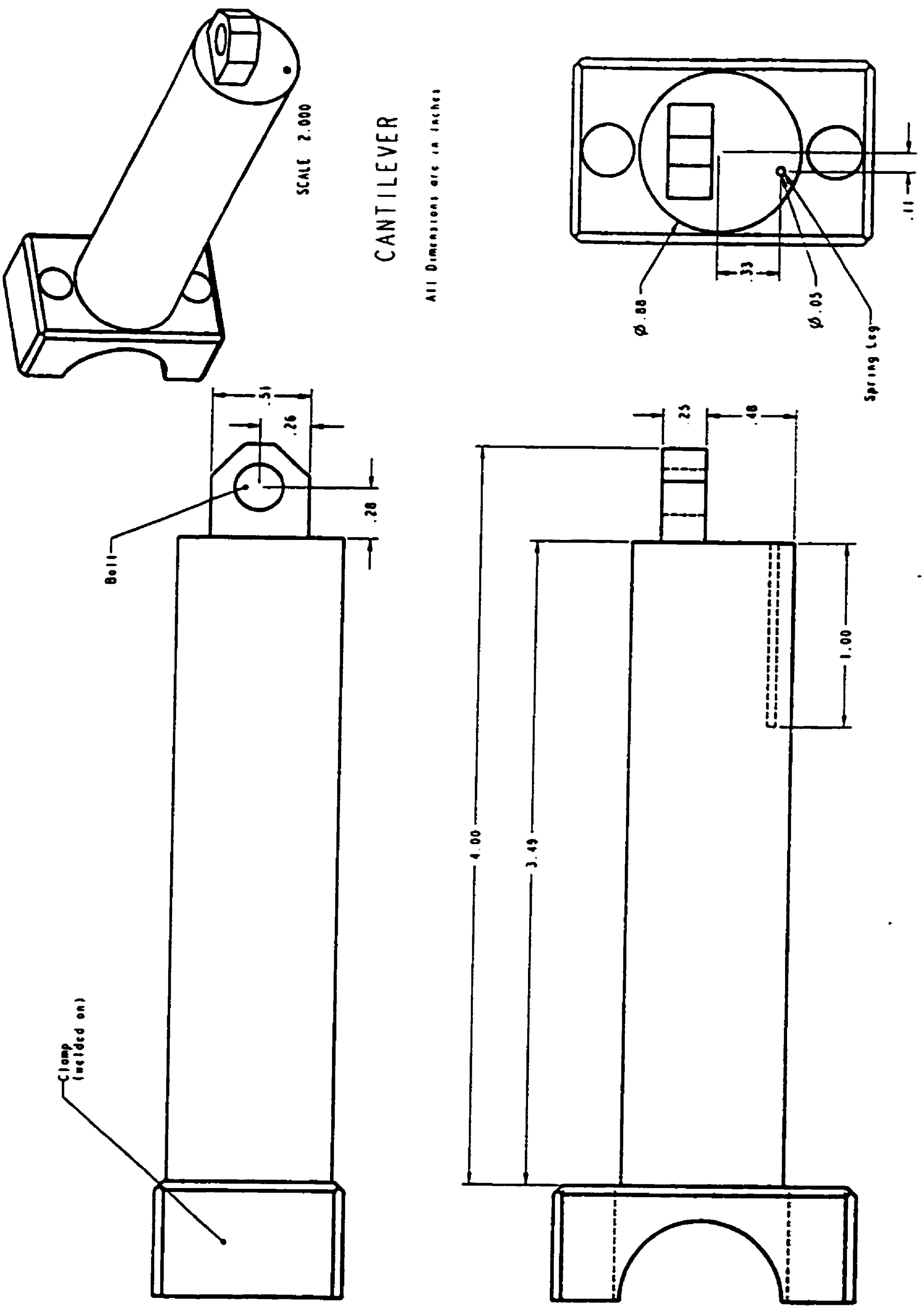
Anti-Tipper Assembled onto Wheelchair

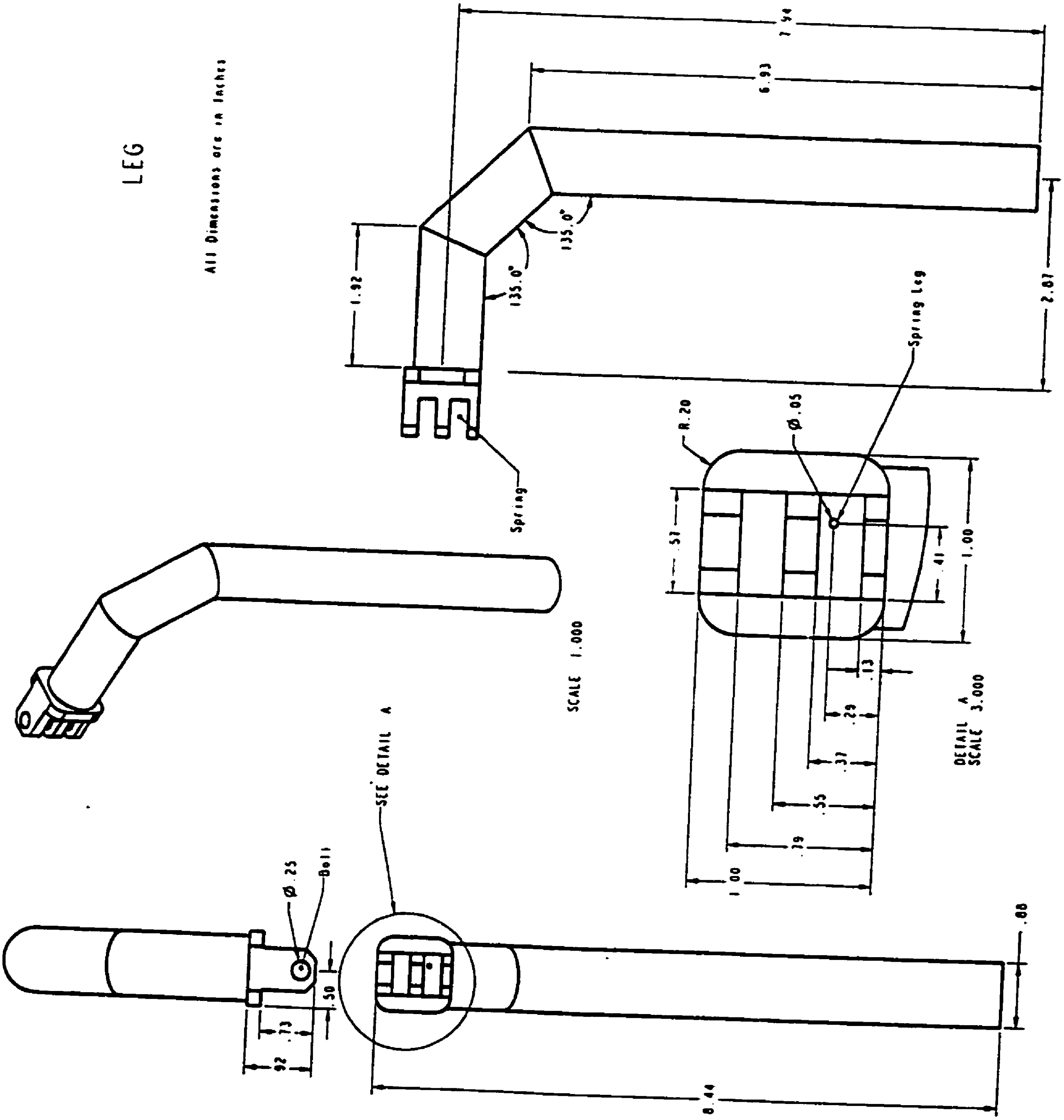

ANTI-TIPPER ASSEMBLY
6.70 (Variable Distance)
3.00 (Variable Distance)
Spring
8.34
7.98
Plastic Sleeve
.25

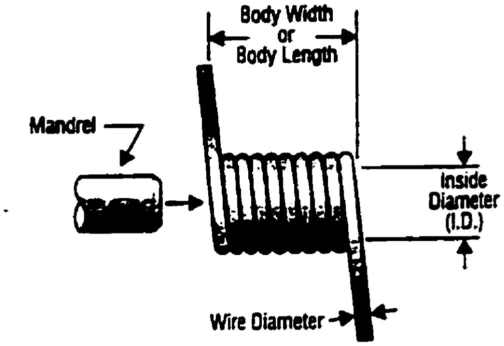


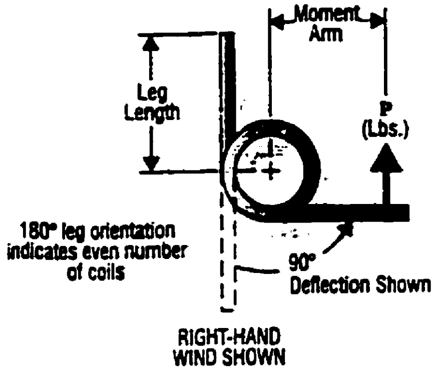
CLAMP

All Dimensions are in Inches


CANTILEVER
All Dimensions are in inches
SCALE 2.000
Ball
Clamp (welded on)
Spring Leg
Ø.88
Ø.05
.33
.11
.51
.26
.28
.25
.48
4.00
3.49
1.00

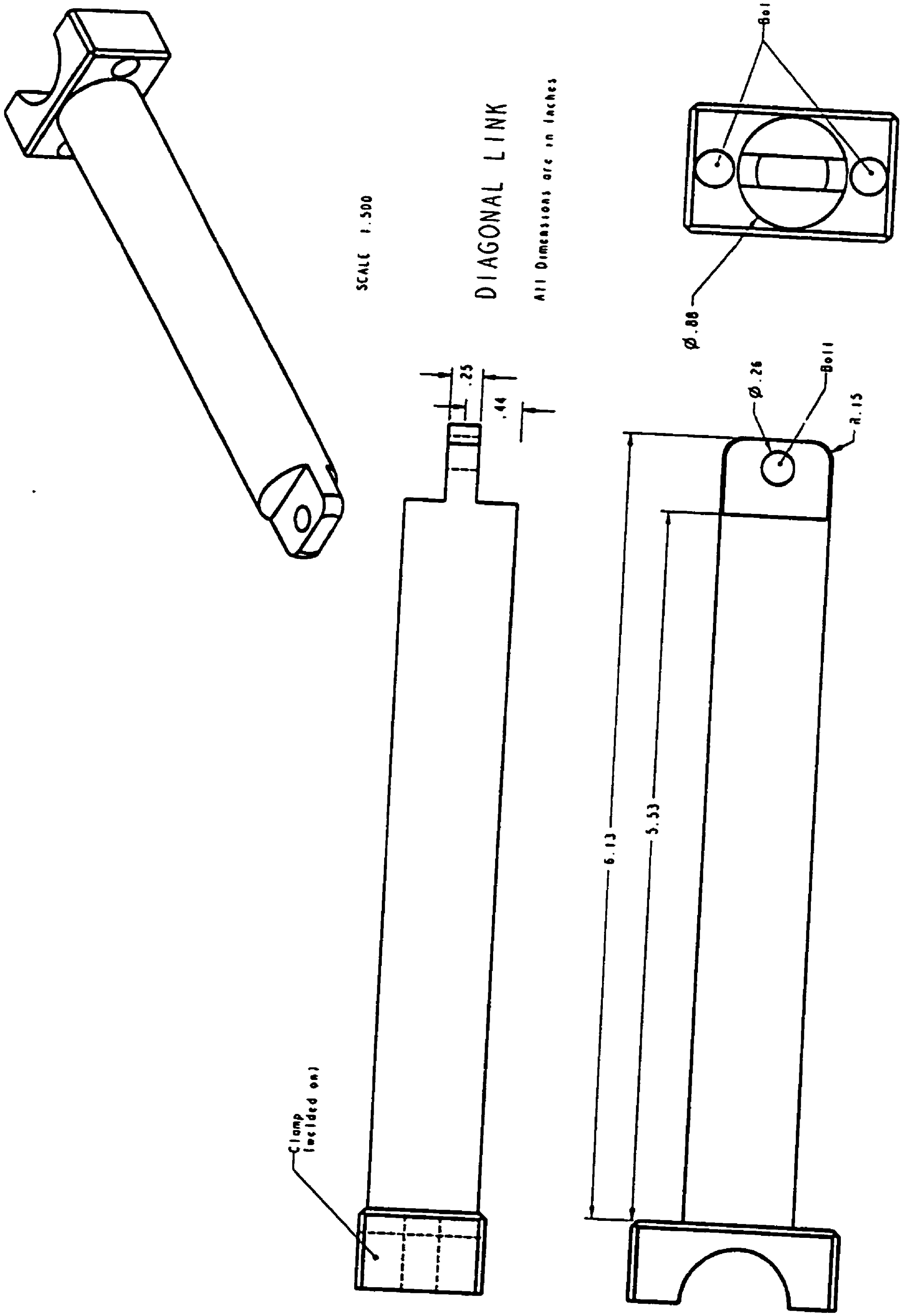

LEG
All Dimensions are in Inches
7.94
6.93
1.92
135.0°
135.0°
135.0°
2.07
Spring
Spring Leg
R.20
Ø.05
.57
.41
1.00
.13
.29
.37
.55
.79
1.00
DETAIL A
SCALE 3.000
SCALE 1.000
SEE DETAIL A
Ø.25
Bolt
.50
.73
.92
.88
8.44

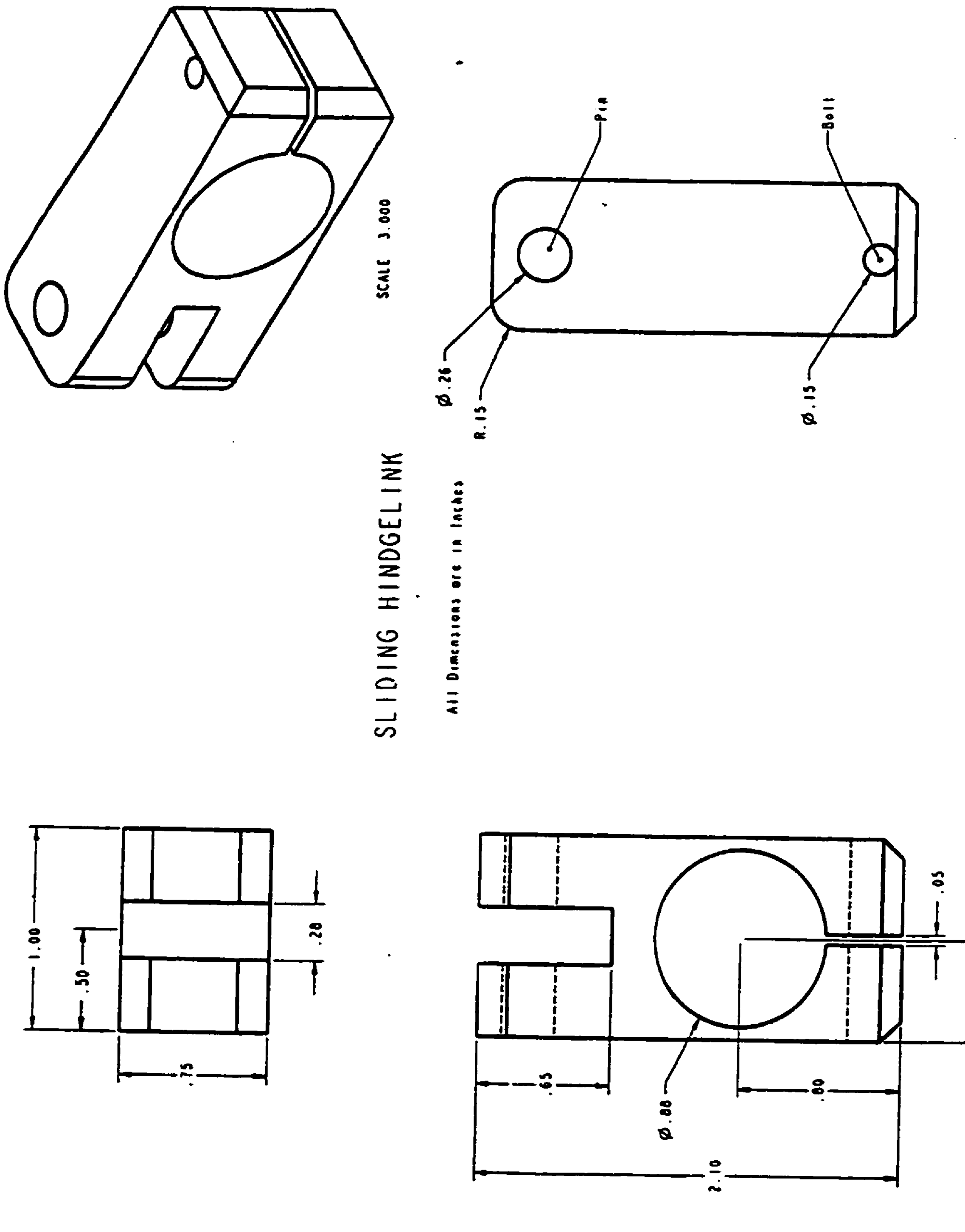




Torsion Spring Specifications

Inside Diameter: 0.267 Inches
Outside Diameter: 0.357 Inches
Wire Diameter: .045 Inches
Leg Length: 1.3 Inches
Body Length: 0.26 Inches
Spring Rate: 0.02226 In•Lbs/Deg.
Material: Stainless Steel


DIAGONAL LINK
All Dimensions are in Inches
SCALE 1.500
Bolt
Ø.88
Ø.26
Bolt
R.15
.25
.44
6.13
5.53
Clamp
(welded on)


SLIDING HINDGELINK
All Dimensions are in Inches
SCALE 3.000
Pin
Bolt
Ø.26
R.15
Ø.15
1.00
.50
.20
.75
.65
Ø.88
.80
2.10
.05
.50

Non-mechanical Solutions

The are several possible solutions from an administrative perspective that are aimed at preventing accident before they happen.

Equipment Prescription

The most important policy that can be implemented is that of prescribing an assistive device for every individual. Everybody's needs and problems are different and in many ways unique. The *Wheelchair Design and Selection Issues* and *Management Issues* sections of this report go over the prescription guidelines in more detail. Here is a summary of equipment prescription issues:

- Formation of a multidisciplinary group of individuals whose goal is to help the user.
- The group consists of the occupational therapist, the user, user's associates, vendors, caregivers, doctors and possibly rehabilitation engineers.
- The user must be subjected to a thorough evaluation.
- The user needs and goals must be established.
- Once the problem is isolated, proper technology can be matched with the user (if technology is even needed).
- The line of communication between the user and the prescribers must remain open as the user's needs change with time.

Wheelchair Envelope

The staff and user need to be aware of the wheelchair envelope concept. This means that every wheelchair-user system ergonomically requires a certain amount of space for functionality. This is known as the wheelchair envelope. It is an imaginary three-dimensional space that that can be divided into three sections. In each section the user can perform a task with a different degree of difficulty that in another section. Figure 25 depicts the three areas in a cross-section of the wheelchair envelope:

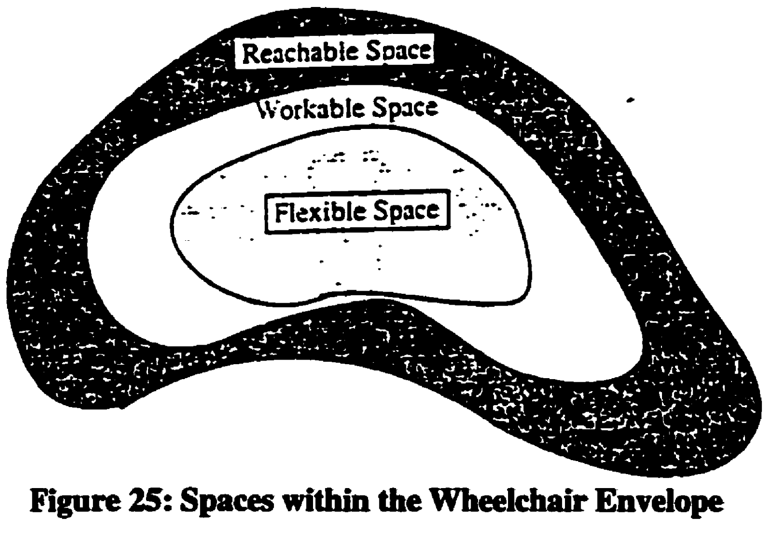


Figure 25: Spaces within the Wheelchair Envelope

The wheelchair envelope includes:

- *The flexible space*: The area in which a given task or activity can be performed in two or more ways.
- *The workable space*: The area in which a given task or activity can be performed, usually in only one way.
- *The reachable space*: The are that a person can reach. At the extremes of the reachable space, one is able only to touch an object, but not to manipulate it.

If users stretch beyond their reachable space, i.e. beyond their envelope, it may result in a hyperextension of their joints, or most probably a tip or a fall. It is best to keep all residents' activities within their flexible space or workable space. This includes reading, eating, socializing, playing cards, sitting by the table, etc. Everybody's envelope is different. The wheelchair envelope is a function of three characteristics:

- *Anthropometric measurements of user*: Everyone has different body dimensions, different reach and different location of the center of gravity.
- *Physical capabilities of user*: Every user has different abilities and capabilities. This includes strengths, maladies and perception.
- *User's wheelchair dimensions*: Wheelchairs come in different sizes. Due to comfort and stability reasons, different wheelchairs present limitations on what the user can do safely.

To determine each individual's wheelchair envelope, they can be accurately measured using goniometers and video/computer equipment. The other alternative would be to consult anthropometric data, Figure 26:

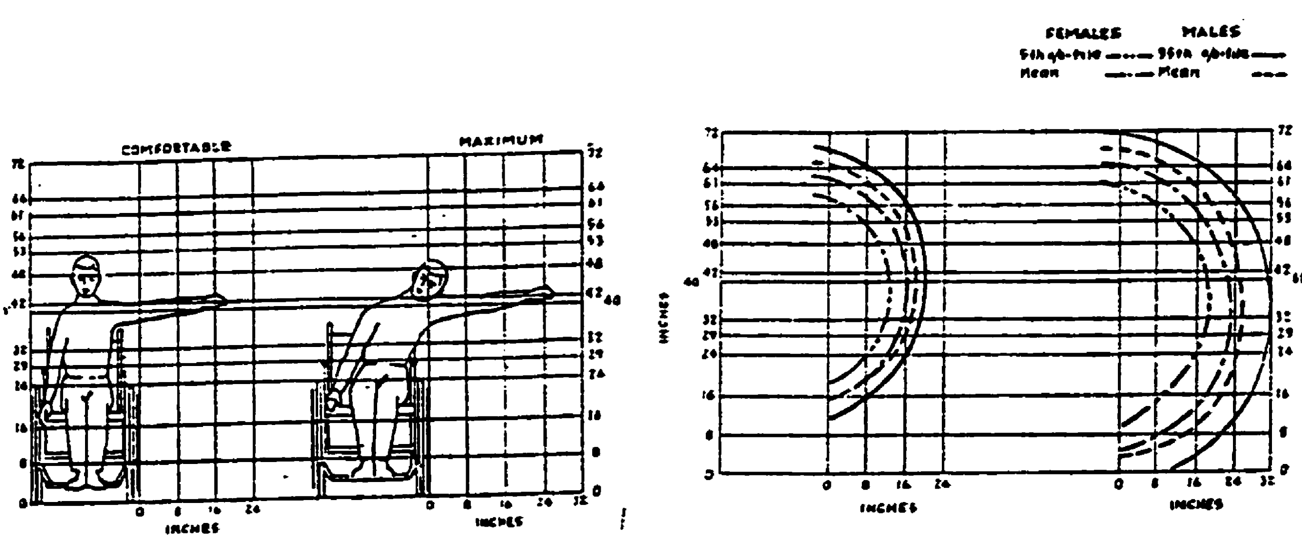


Figure 26: Examples of Reach Data for Determination of the Wheelchair Envelope

Once the envelope is determined in terms of measurements, it may look something like Figure 27:

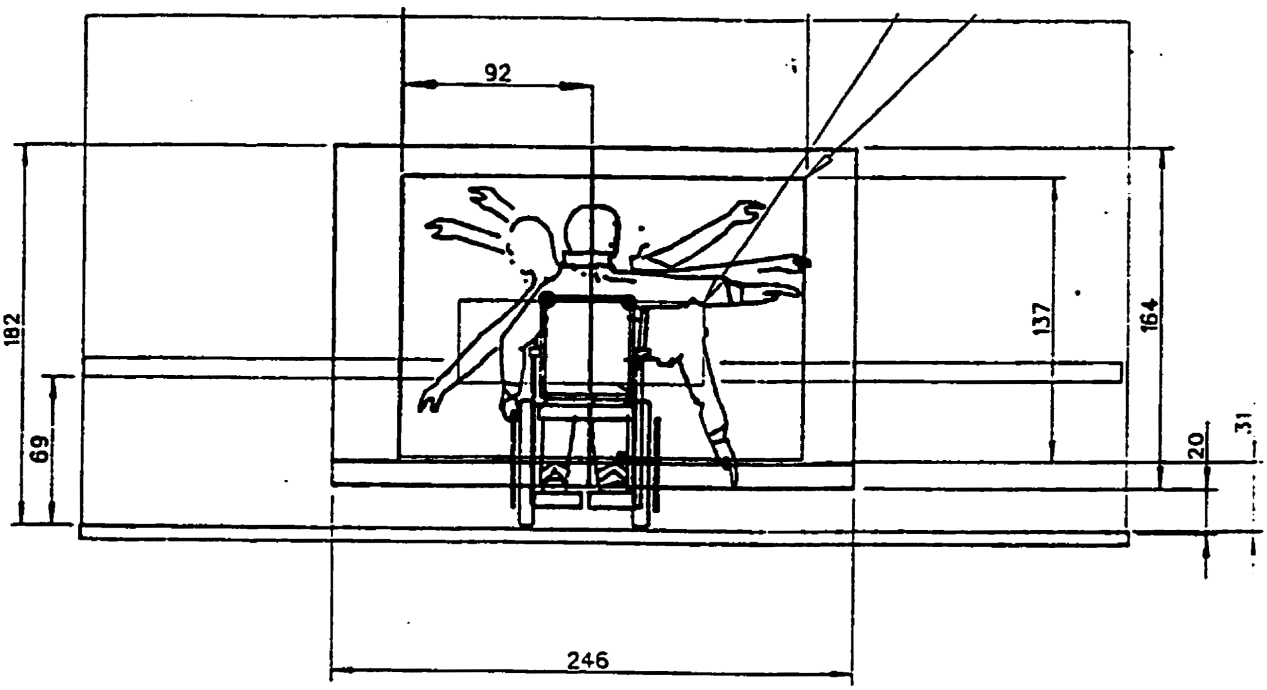


Figure 27: Example of a Wheelchair Envelope

In the above figure, the outermost box defines the boundaries of the envelope, the two smaller boxes are the workspace and flexible space. Once a user reaches beyond this envelope, the center of gravity shift beyond the base of the wheelchair, which will result in a likely tip. In most reaching cases there is a motive to reach: to achieve a task. Sometimes this task is to reach a piece of furniture or railing that is beyond their envelope, causing a fall. The person would not fall if:

1. The task was eliminated.
2. The task was within the envelope.

Since elimination of all tasks and activities in the lives of seniors is unrealistic, the best alternative would be to make sure that every user performs within their envelope. This also means that an environment where potential motives for reach are outside user envelopes must be monitored. These settings include large rooms with multiple objects (to be reached) at various distances such as a lounge room.

Summary of the wheelchair envelope:

- Every user must be measured, and their capabilities established.
- Using anthropometric data, their wheelchair envelope should be determined.
- All user activities must be performed within their envelopes.
- All unnecessary activity, objects or obstructions should be located beyond the envelope.
- All area were potential activity may occur but is beyond a given envelope, should be monitored.
- With experience, all caregiver will develop a 'feel' for a given user's envelope.

Information System

Information and communication networks are integral attributes of a well-managed organization. There must be an adequate system of data collection, processing, interpretation and solution implementation based on these results. This can be accomplished through the following techniques:

- *Incident reports*: All accidents and incidents must be reported using a standardized, updated form. The must be completely filled out with emphasis place on the description and accuracy. All incidents must be catalogued on a database. The computerized data should be set up in a way that facilitates statistical extraction. Statistical variables should include times, dates, types of accident, types of injury, types of treatment, age, gender, location, repeat fallers (names of fallers), and categorized details of the accident. From these statistics it will possible to identify problem variables more easily, implement a decided solution and monitor progress.
- *Equipment inventory*: All wheelchair equipment and accessories must be catalogued. Every piece and part must be associated with the following factors: it's age, manufacturer, it's user, condition of the user, it's current location, it's current maintenance and functional status, and all accidents associated with it. This database must be constantly updated. From this database it is possible: to keep track of all equipment, to see whether the equipment satisfies the users needs, and to identify any possible problems in the future.
- *Employee surveys*: Employee feedback is important because they are the closest to all accidents and users. Survey's should be periodically given to employees to determine: possible accident locations, living conditions, working conditions, job satisfaction of employees, problem areas and possible suggestions for improvement.
- *Evaluation of facility*: Periodic visits from health inspectors, building inspectors, AADL, engineers and maintenance specialists could provide valuable information on the 'wheelchair-friendliness' of the facility. Possible trouble area could include: poor riding surface, changes in riding surface, changes of levels, frequent obstructions, poor lighting, blind corners and narrow areas.

Education and Intervention

Staff education is important for identification of problems and prevention of future accidents. Education should be focused on the following areas:

- *Knowledge of wheelchair issues*: Many of the issues associated with wheelchairs should be known to caregivers. These issues include criteria, standards, wheelchair components, and operation of assistive devices.
- *Understanding user needs*: Caregivers and the staff are part of a multidisciplinary team whose goal is to evaluate the user condition and prescribe a suitable technological aid. The caregivers must see all the reasons for the user's problem, not just treatment of an apparent symptom.
- Wheelchair maintenance: Caregiver must be aware of existing wheelchair components, their functionality, their potential problems, and how to fix them.
- *Identification of problem location and accident potential activities*: The staff must be informed of what causes accidents, how they happen, where they happen, contributing factors, what are the effects, how can they be prevented.
- *Procedure manual*: There has to be some form of standardized reference that includes procedures on reacting to accidents and precautionary measures.

It must also be stated that most of this information is contained within this report and the sources listed in the reference section.

Summary

Possible policy solution for lateral stability include:

- Prescription of all assistive devices.
- The recognition of a wheelchair envelope.
- Information collected and processed efficiently.
- Education of the staff about wheelchair issues and safety.