Powered wheelchair safety support on CEAL simulator

Powered wheelchair safety support on CEAL simulator

Ing. J. Eisinger (553104)

DCT.2007.089

Short internship report

Supervisor: Prof. Dr. Ir. M. Steinbuch
Coaches: Dr. Sunjoo K. Advani

Eindhoven University of Technology
Department of Mechanical Engineering
Dynamics and Control Group

Eindhoven, June 26, 2007

Preface

This report, ”Powered wheelchair safety support on CEAL simulator environment”, covers the short internship report study of the author, which has been performed within the division of Dynamics and Control of the faculty of Mechanical Engineering at the Eindhoven Technical University. During this project I learned a lot of how to handle a methodical design proces, determine requirements and to get insight of a large complexe project. To come to a suitable design i've had help from Marcel Wittebrood, who helped me to go to the right track. Besides Marcel Wittebrood, I would like to thank Maarten Steinbuch, Sunjoo Advani, Piet Teerhuis and Mario Potter for given me this assignment and support.

J.Eisinger
Eindhoven, October 2006

Summary

The subject of this trainee ship is the development of a mechanisme to safely test electrical driven vehicles like powered wheelchairs on the Challenging Environment Assessment Laboratory (CEAL) simulator environment. To come to the recommendations for designs, first primarily of concept investigation is used to get insight of the requirements and to investigate the situation were the powered safety support will work and which tasks the powered wheelchair must perform on the platform. Using this information functions are elaborated which the powered wheelchair safety support must preform. These functions are performed by procedures, all these procedures are combined in the morphologic overview. Possible designs are derived from the morphologic overview and valued against the variable requirements. In this way the design is determined keeping the design level global to prevent poorly designs to be elaborated too far.

The recommendation for a suitable design consists out of 3 telescopic devices with adjustable damping and an fixed end restriction. These telescopic devices are connected through spherical joints to the powered wheelchair and to the x-y tracking mechanisme to give freedom of movement. The damping in these telescopic devices are used to absorb the kinetic energy remaining after braking the powered wheelchair along the allowable braking distance and to bring the wheelchair to a complete stop. The telescopic devices will also prevent the powered wheelchair from tipping over and will hold the powered wheelchair when it reaches an incline of 15°. The fixed end restriction in the telescopic devices will prevent the powered wheelchair from dropping from the platform when the platform malfunctions and reaches an incline of 45°.

Contents

Chapter 1

Introduction

IDT is a small company developing a large project - the Challenging Environment Assessment Laboratory (CEAL), to enable researchers to investigate stability and balance of normal and impaired persons, to develop techniques for the prevention of falls, to evaluate rehabilitation processes, and to develop assistive devices. The evaluations will be conducted on a unique simulator platform. The subjects - from children to elderly persons - will be placed on a moving platform and perform specific tasks, such as walking or riding a wheelchair. A six-degrees-of-freedom motion system will cause the platform to move in slow movements (such as a steady-state tilt of up to 25), or rapid, short bursts, making it possible for researchers to induce neuro-muscular reactions similar to those prior to a fall. On the CEAL the subject is placed in a wheelchair and an assistant is standing in the vicinity. Both are secured by a safety harness mechanism. Motion sensing system monitor the subject's kinaesthetic movements, as well as the motions of the wheelchair. Safety is a critical issue in this program. Since the subjects will be performing their tasks on a moving platform with high acceleration capabilities, it is crucial that the individual (up to two persons) are supported by a Safety Harness System. At the same time, the powered wheelchair may not be restrained by the safety harness system. Therefore, an intelligent, careful and systematic design of the system is required. The walking tasks of the subject and assistant will also be performed with help from a safety harness. This will be an X-Y gantry-type mechanism that tracks the subject and maintains the attachment point approximately above the person's head. For the wheelchair tasks, a separate safety harness mechanism is required, which will couple to the X-Y mechanism described above. It is important for both these systems to work together and provide the required safety and redundancy. This document will describe the design proces with respect to the connection of the powered wheelchair to the tracking system by means of a adapter, the powered wheelchair safety support system.

1.1 Outline of the report

This report is organized as follows. In chapter 2,the primarily investigation is discussed in terms of environmental requirements, platform motions and assumptions. In chapter 3, the test case will be formulated in static test case and dynamic test case and the normalized dimensions according to ISO 7175-5 are used to determine the center of gravity and the position of the center of gravity at maximum platform incline. In chapter 4, the methodic design proces is used the come to a suitable design meeting the requirements. Finally, in chapter 5 conclusions and recommendations are given.

Chapter 2

Preliminary investigation

In this section the preliminary investigation will be discussed with respect to the powered wheelchair operations in the CEAL simulate environment. Because the powered wheelchair support mechanism will be attached to a x-y tracking mechanisme that is in the proces of being developed, system some of the the requirement consider already the characteristics of that system.

2.1 Required platform environment and devices

- The powered wheelchair safety support will work in the CEAL simulator environment.
- The environment can be chanced by placing different pallets:
  - Flat floor with obstacles.
  - Ice Chamber with different surfaces.

2.2 Required environmental conditions

- Temperatures -10 ° C to + 40 ° C.
- 0-99 % relative humidity.
- Dry, Snow and or rain
- Adjustable wind velocity (ventilator)

2.3 Required platform motions

- The Platform can translate in all directions
- The platform can be placed in an fixed incline of 15°.
- The platform can be placed with slowly increasing incline to the maximum of 15°.
- The platform can be placed in an fixed incline of 5° when the ice/snow chamber is installed.

- Accelerations during normal motions are up to 10 m/s^2 in linear directions. For failure modes (sudden valve closure), accelerations can be as high as 2.5 g (although only for a small amount of time). [1].
- Disturbing movements at key moments, for example standing up out of the powered wheelchair or entering the platform.

2.4 Powered wheelchair requirements

- The maximum speed of a powered wheelchair 1.5 m/sec
- The travel distance to accelerate is 2 m
- The powered wheelchair can make a vertical movement (seat rise) of 450 mm

2.5 Required Obstacles

- 10-18 cm curbs.
- Snow powder/packed/slush.
- Mud/bare ground/sand.
- Wet floor.
- Ice(solid) floor.
- Asphalt floor.
- Uneven terrain.
- Potholes located in floor.

2.6 Working conditions:

- The powered wheelchair can be operated by the subject alone or under the supervision of a competent person.
- The powered wheelchair must be capable of driving freely on the platform surface.
- The powered wheelchair may never tip over due to a malfunction or disturbance of the platform.
- The powered wheelchair must be fixed on the platform and switched off during an malfunction [2].

[1] Exact accelerations will be used in future calculations. This will be done in close consideration with the motion system supplier

[2] Malfunction is defined here as:The powered wheelchair safety support shall respond to motion system failures or even a failure of the safety support system itself. Motion system failures can occur when the motion system receives wrong commands from the host computer, during power failures and during hardware failures.

2.7 Assumptions

- One subject in a powered wheelchair, and the powered wheelchair itself with a total mass of 300 kg
- During malfunction the accelerations could achieve a value of up to 2.5G in XY-directions or 3.5G in Z-directions.
- Maximum speed of the powered wheelchair is 1.5 m/s

Chapter 3

Required experiments

This chapter will describe a possible test case with respect to a powered wheelchair on the CEAL simulator environment.The test case will address possible tests that can be preformed by the powered wheelchair on the platform. The goal is to derive a possible design for the powered wheelchair safety device that is capable of fulfilling the test case requirements.

3.1 Degrees of freedom of a powered wheelchair on the CEAL

- x direction is forward and backwards movement
- y direction is sideways movement
- z direction is up and downward movement
- ϕ rotation is rotation about the x axis
- φ rotation is rotation about the y axis
- ψ rotation is rotation about the z axis

There are 6 degrees of freedom were the translation in z direction is constrain due to the fact that the powered wheelchair is driving on a flat floor. The 2 other translation degrees of freedom are unconstrained. The rotation about the z axis is unconstraint, ψ the powered wheelchair can circle around on the platform. The goal is to make sure that the powered wheelchair will not tip over so that ϕ and φ are constraint.

3.2 Dynamic curb test in forward direction

When a powered wheelchair is driving freely on the platform within the boundary of the horizontal platform dimensions of 5000 mm in diameter in forward direction with a maximum speed of 1.5 m/sec the powered wheelchair can collide with a curb. This curb has a minimum height of 100 mm and a maximum height of 180 mm. The platform can have a maximal static incline of 15° on ice 5°. Colliding with the curb will abrupt stop the powered wheelchair and the wheelchair will try to rotate φ degrees. The goal is to minimize φ, when φ is greater then 15 °the powered wheelchair safety support must prevent the powered wheelchair from tipping over completely. When φ is greater then the allowable incline the powered wheelchair safety support must fix the wheelchair on the platform and must stop the motors of the powered wheelchair. The powered wheelchair must have 2 meter travel distance to accelerate to his maximum acceleration and must be able to a stable stop

3.3 static curb test in sideways direction

The platform will brought up to incline of 15° on ice 5°. At this incline the powered wheelchair may not tip over sideways or slide sideways. When the powered wheelchair reaches a incline of 15° the safety support will fix the powered wheelchair on the platform.

3.4 static curb test in forward direction

The platform will brought up to incline of 15° on ice 5°. At this incline the powered wheelchair may not tip over forwards or backwards. When the powered wheelchair reaches a incline of 15° the safety support will fix the powered wheelchair on the platform.

3.5 Dimensions of the powered wheelchair

3.5.1 Recommended maximum limits according to ISO 7176-5

To determine the dimensions of the powered wheelchair safety support we need to know the dimensions of the powered wheelchair. Since the CEAL simulator is a test facility to test prototypes wheelchairs the dimensions are still unknown. Therefore we make an assumption for the dimensions of the powered wheelchair. To make a reasonable assumption we use the ISO norm for wheelchairs, powered wheelchairs and mobile scooters ISO 7176-5 and use the worse case scenario. In the figure 3.1 and 3.2 the recommend maximum limits are given.

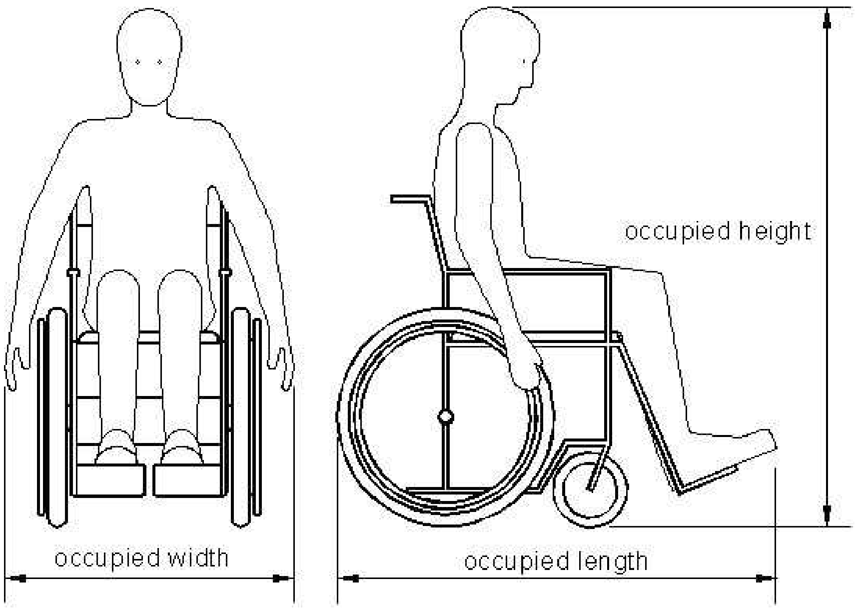

Figure 3.1: Dimensions of the wheelchair when occupied

	Manual wheelchair	Electrically powered wheelchair		
		Class A	Class B	Class C
Occupied length	1300	1300	1300	1300
Occupied width	800	700	700	700
Occupied height	1600	1600	1600	1600

Figure 3.2: Recommended maximum limits (in mm)

3.5.2 Center of gravity of the powered wheelchair with occupant

To make an assumption for the center of gravity of the powered wheelchair occupied with a person we use the assumptions of the previous section. For the simplicity we assume that the wheelchair with occupant is symmetrical. Since the occupant length is the maximum length of 1300 mm we assume that the distance between the front axel and rear axel is 1000 mm. The occupant width we use the half width of 350 mm. For the height we take in to account that the seat of the powered wheelchair can rise 450 mm in vertical direction. This displacement results in a vertical shift of the center of gravity of 225 mm this contribution is added with the half occupant height of 800 mm so the total height will be 1025 mm.

3.5.3 Position of center of gravity during static platform positions

The maximum angle the platform can have is 15°, the maximum angle of the powered wheelchair is 15°. This will result in the maximum angle of 30° referred to the fixed world. In figure 3.3 the static situation is shown for the front view in one direction assumed here is that the tilt in the other direction is equal to the shown situation.

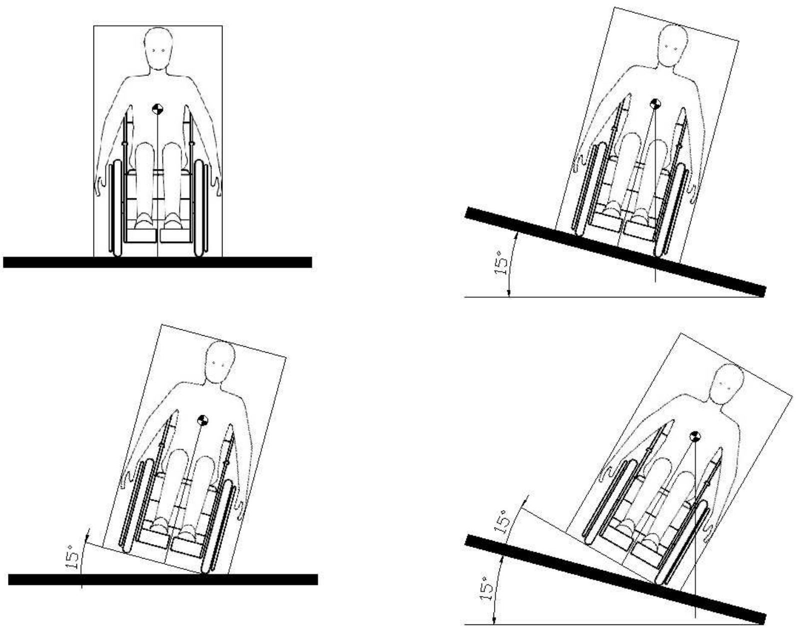

Figure 3.3: Position center of gravity tilt sideways front view

For the side view the situation is shown in figure 3.4 and 3.5. Here we assumed that the center of gravity is located in the middle of the pitch between the front axel and rear axel.

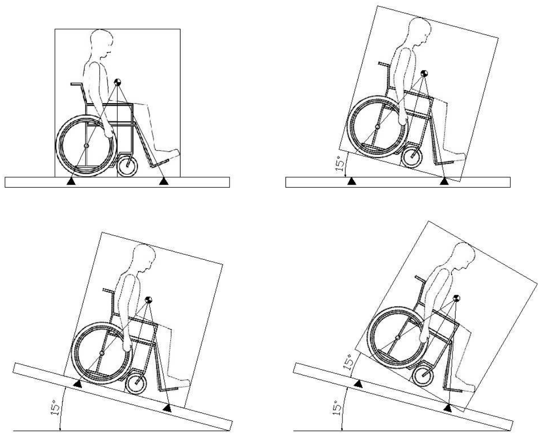

Figure 3.4: Position center of gravity tilt forward side view

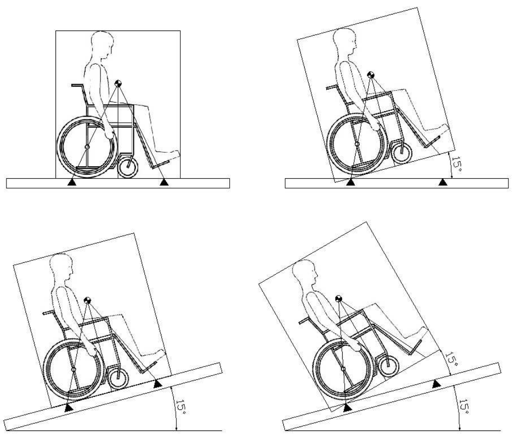

Figure 3.5: Position center of gravity tilt backward side view

Chapter 4

Design proces

In the next chapter the design proces will be discussed. For the design of the powered wheelchair safety support we used the methodical design proces according to Prof dr ir H.H van Kroonenberg [1]. The choice for a methodical design proces is made because there is still allot unknown about the complete CEAL simulator environment. There are many requirements that may be changed during the progression of the total design. To make sure that the design of the powered wheelchair will fit in the total design this methodical approach will be applied so that when requirements change the total overview is kept.

4.1 Design proces on global level

The design proces will start on global level to make a premature selection for designs. This prevents that imperfectly designs are elaborated to far. When designs are derived on global level the design will go on to a deeper level.

The first step is to determine the need for the design for the powered wheelchair case:

To Test safely a electrical driven vehicle such as a powered wheelchair and robotic nurse in a CEAL simulator environment

Derived from the need the goal can be determined for the powered wheelchair case this will result in:

Design a mechanism that secures the safety of a electrical driven vehicle such as a powered wheelchair and robotic nurse in a CEAL simulator environment

The next step is the problem-oriented phase were we take a closer look at the problem and derive a set of requirements.

In this case we need to find a way to drive around freely on a bounded surfaces with obstacles and different foundations were in no case the powered wheelchair can drop from the bounded surface or tip over. So we need to find a mechanisme that brakes the powered wheelchair and that prevents the powered wheelchair from tipping over. The platform is provided with a fall arrest system that prevents walking patients from falling. This mechanisme can probably be used for the powered wheelchair case. The fall arrest system is also provided with a tracking system. This system makes sure that the fall arrest system stays above the patient at all times. Such a system should also be applied for the powered wheelchair case to make sure the position of the powered wheelchair is known at all times. Another problem that can occur is the connection of the mechanisme to the powered wheelchair since it should be possible to test different powered wheelchair with different shapes and dimensions.

4.2 Requirements for powered wheelchair safety support

The requirement are determined from the preliminary investigation with the need and goal in mind. The requirements are derived using the following key words with safety as the main priority. The requirements can be found in appendix A

- General operations
  - Required operation
  - Reliability
  - Safety
  - Quality
  - Maintainability
- Manageability
  - Dimensions.
  - Weight.
  - Mechanical payload.
  - Environmental conditions.
- Use scenario specific.
  - Motion platform.
  - Powered wheelchair.
  - Tracking system.
  - Powered wheelchair safety support.
  - Supporting structure.
- Use case specific
  - Dynamic testing.
  - static testing.
- Research pallets specific

  - Flat floor with obstacles.
  - Ice Chamber with different surfaces.
- Failure modes
  - Motion system.
  - Powered wheelchair safety support.
  - Tracking system

4.3 Functions of the powered wheelchair safety support

For the powered wheelchair safety support to work properly the system has to be able to preform functions. The collaboration of the individual functions will result in a system that will fulfill the need and goal. For each function solutions will be determined that will preform the function. The concept solutions will be trade-off against the requirements. The powered wheelchair safety support problem can be formulated into functions:

1. Braking
2. Angle restriction
3. Connection to x-y tracking mechanisme
4. Connection to Powered wheelchair
5. Motion tracking system

4.3.1 Braking

There 4 primary ways of braking the powered wheelchair when driving on the simulator platform:

1. Using the break system of the powered wheelchair itself
2. Braking the powered wheelchair using a mechanisme on the platform using:
   - Friction pads
   - Vacuum pads
   - Magnetic pads
3. Braking the powered wheelchair using a mechanisme on the tracking system/fall arrest system.
4. Combination of above mentioned braking systems

4.3.2 Angle restriction

There are 2 primary ways of preventing the powered wheelchair from tipping over. Both the procedures may be passive or active meaning that the procedure can be motion controlled or not. This will come out when the design goes into a deeper level.

1. Using a mechanisme that will stop the rotation by pushing to the platform
2. Using a mechanisme that will stop the rotation by pulling at the tracking system/fall arrest system.

4.3.3 Connection to x-y tracking mechanisme/fall arrest system

1. Cables
2. Bars/Stanchions
3. Telescopic device

4.3.4 Connection to Powered wheelchair

1. Cables
2. Bars/Stanchions

4.3.5 Motion tracking system

1. Visual tracking system
2. Joystick tracking system
3. Local GPS

4.4 Design Choices

Using the morphologic overview shown in figure 4.1 design choices can be made. In this case 7 designs are chosen but there could be more derived. These design choices are classified using the requirements so that the best design can be chosen.

4.4.1 Design A

Description:

This design uses de brake system of the wheelchair. For the angle restriction a frame should be mounted around the wheelchair with static angle restriction blocks mounted so that the wheelchair is restricted when it reaches a angle of 15°. A variant for this system is a controlled angle restriction in this case a cylinder can be attached to the angle restriction block so when the wheelchair reaches a angle of 15° the angle of the wheelchair is restricted and the cylinder pushes the wheelchair back against the platform. The powered wheelchair is connected to the frame with bars and the frame and wheelchair are connected to the supporting structure with cables to prevent that the powered wheelchair can fall from the platform. The position of the wheelchair is monitored by means of a visual tracking system.

4.4.2 Design B

This design uses friction pads mounted on the static angle restriction blocks the required normal force is achieved by the total mass of the powered wheelchair and safety support. The area needed for the friction surface has to be large enough to bring the powered wheelchair to a total stop when the powered wheelchair reaches the maximum allowable acceleration. The powered wheelchair is connected with the supporting structure by means of cables and connected with the safety support by means of bars or stanchions. The position of the wheelchair is monitored by means of a visual tracking system.

4.4.3 Design C

This design uses friction pads mounted on controlled angle restriction with activated cylinders. The normal force is achieved by the total mass of the wheelchair and safety support plus a force generated by pushing against the safety support. Therefore the connection with the powered wheelchair and the supporting structure is achieved with bars or stanchions. The connection with the powered wheelchair and the safety support is by means of bars or stanchions.

4.4.4 Design D

This design uses a brake mechanisme located in the supporting structure. For the angle restriction the angle of the powered wheelchair is transported to a utensil above the powered wheelchair. This utensil is connected with the supporting structure by means of a telescopic device with fixed distance limitations. The powered wheelchair is connected with the utensil with bars or stanchions in a way that the utensil stays above the powered wheelchair at al times. The position of the utensil is monitored by means of a joystick device. The rotation of the utensil is unconstraint by means of a clutch. in case of a malfunction the clutch is released and the rotation is then constraint.

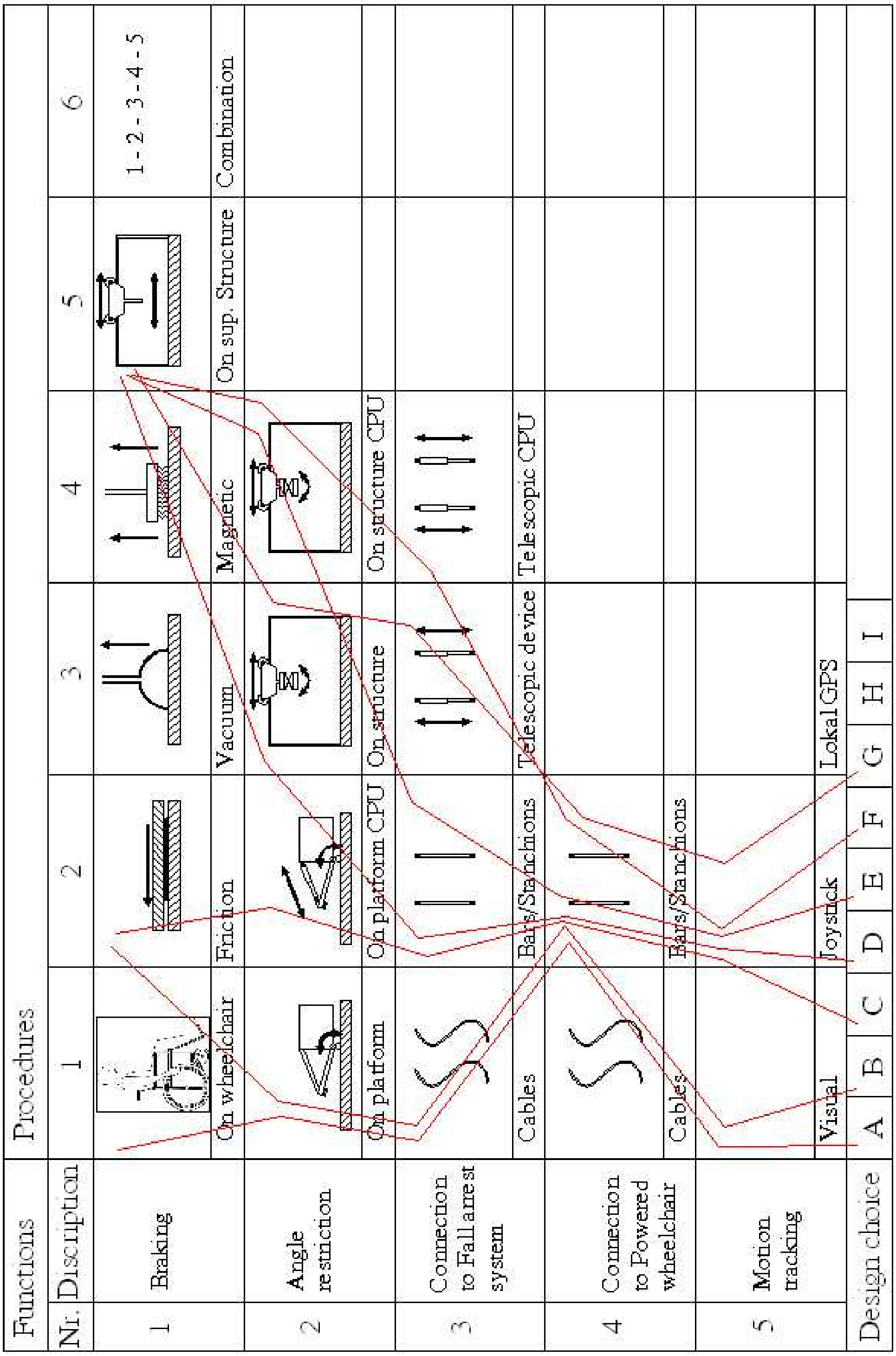

Figure 4.1: Morphologic overview

4.4.5 Design E

This design uses a brake mechanisme located in the supporting structure.For the angle restriction the angle of the powered wheelchair is transported to a utensil above the powered wheelchair. This utensil is connected with the supporting structure by means of a actuated cylinders and fixed distance limitations. The powered wheelchair is connected with the utensil with bars or stanchions in a way that the utensil stays above the powered wheelchair at al times. The position of the utensil is monitored by means of a joystick device.The rotation of the utensil is unconstraint by means of a clutch. in case of a malfunction the clutch is released and the rotation is then constraint.

4.4.6 Design F

This design uses a brake mechanisme located in the supporting structure. The angle restriction is accomplished by means of actuated cylinders with fixed distance limitations. These cylinders connect the powered wheelchair with the supporting structure.The position of the powered wheelchair is monitored by means of a joystick device. The rotation of the powered wheelchair is unconstraint by means of a clutch. in case of a malfunction the clutch is released and the rotation is then constraint.

4.4.7 Design G

This design uses a brake mechanisme located in the supporting structure. The angle restriction is accomplished by means of actuated cylinders with fixed distance limitations. These cylinders connect the powered wheelchair with the supporting structure.The position of the powered wheelchair is monitored by means of a joystick device. The rotation of the powered wheelchair is unconstraint by means of a clutch. in case of a malfunction the clutch is released and the rotation is then constraint.

Chapter 5

Conclusions and design recommendation

To make a choice from the alternative designs the designs are classified against the variable requirements in a choice table. Most of the requirements are fixed and any design must fulfill these requirements therefore the variable requirements are used to make a good choice.

Requirement	*Design*							
	A	B	C	D	E	F	G	Ideal
Braking on different surfaces	1	2	2	4	4	4	4	4
Safety during a malfunction	1	2	2	4	3	3	4	4
Position monitoring powered wheelchair	2	2	4	4	4	4	4	4
Applicability on different wheelchairs	2	2	2	4	4	4	4	4
Complexity	4	4	4	3	3	3	4	4
Capable of self locking	4	4	4	4	3	3	4	4
Immune for dirt dust snow and water	1	1	1	4	4	4	4	4
Total	15	17	19	27	25	25	28	28
Total %	54	61	68	96	89	89	100	100

In the choice tabel can be seen that design D and design G are the best choices followed by design E and design F. Design D is similar to design E and design F is similar to design G with one differences that E and F are computer controlled and are therefor likely less reliable during malfunction. Design D and design G are mechanical therefor guarantee safety during malfunction.

For designs D and G to work properly it is necessary that the tracking system keeps the x-sled above the powered wheelchair at all times. This requirement is different then for the fall arrest system voor walking persons on the platform. In the walking person case the x-sled keeps the fall arrest cable perpendicular to the fixed world to make sure the person will not swing like a pendulum when the person falls. In the powered wheelchair case it may be possible that the powered wheelchair can swing like a pendulum because of this requirement. To prevent the wheelchair from swinging from the platform the telescopic devices has to be controlled in a way that they keep the powered wheelchair on the platform, stop the wheelchair from moving and to prevent applying large moments on the x-y mechanisme.

Fixating the the telescopic devices will stop the powered wheelchair from moving and will prevent the powered wheelchair from swinging from the platform but will apply large moments on the x-y mechanisme. To reduce large moments on the x-y mechanisme the telescopic devices can be used as sliders with fixed end restrictions and with adjustable damping. In this case when the powered wheelchair safety support has to intervene first the x-y mechanisme and the powered wheelchair wheels have to brake. This abrupt stop will cause the wheelchair to slip further an certain distance. During this movement kinetic energy is absorbed due to friction of the powered wheelchair with the surface, if then the remaining kinetic energy is absorbed in the telescopic devices the powered wheelchair will not swing from the platform. The fixed end restrictions are used only during malfunction of the platform, in this case the wheelchair can never drop from the platform. The fixed end restrictions are installed in a way that the wheelchair can only make an maximum incline of 45 °. Using damped telescopic devices will still apply moments on the x-y mechanisme but considerable less then using fixated telescopic devices. To minimize the moments on the x-y mechanisme we can make use of the fact that the wheelchair creates a dead zone on the x-y movement. The surface used by the wheelchair on the platform makes it able to use more than one x-sled and y-beam or to enlarge the contact distance between the guiding wheels in the rail. Enlarging the contact distance will reduce the moment on the x-y mechanisme and will increase the forces on the structure. The structure is strong enough to handle these forces.

As a recommendation for adjustable damping magnetically damping fluid can be used. This fluid is also used in the shock absorbers in the HUMMER vehicle. The viscosity of the fluid can be adjusted by changing the current. Controlling the current changes the viscosity from "water" till "rock hard". Advantages are that when the fluid has a low viscosity the damping is low in the telescopic devices. In this way the powered wheelchair safety support minimizes the influence on the movement of the powered wheelchair during testing on the platform. When the powered wheelchair safety support has to intervene the current can be controlled which results in a controlled stop of the powered wheelchair.

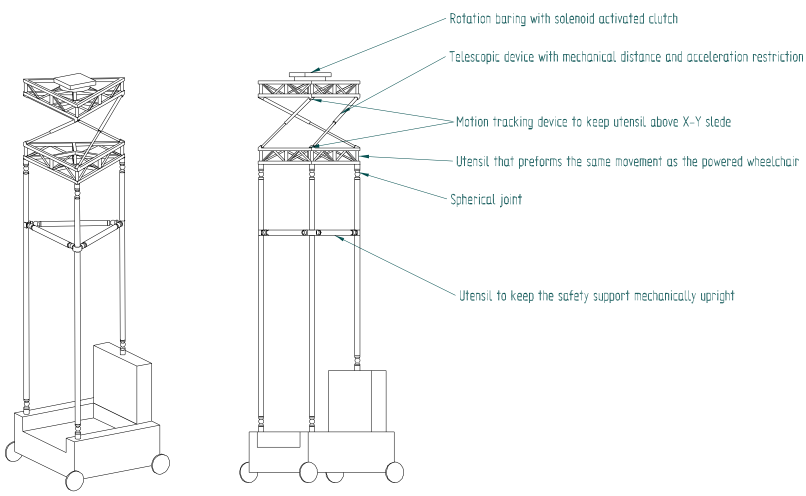

Figure 5.1: Design D

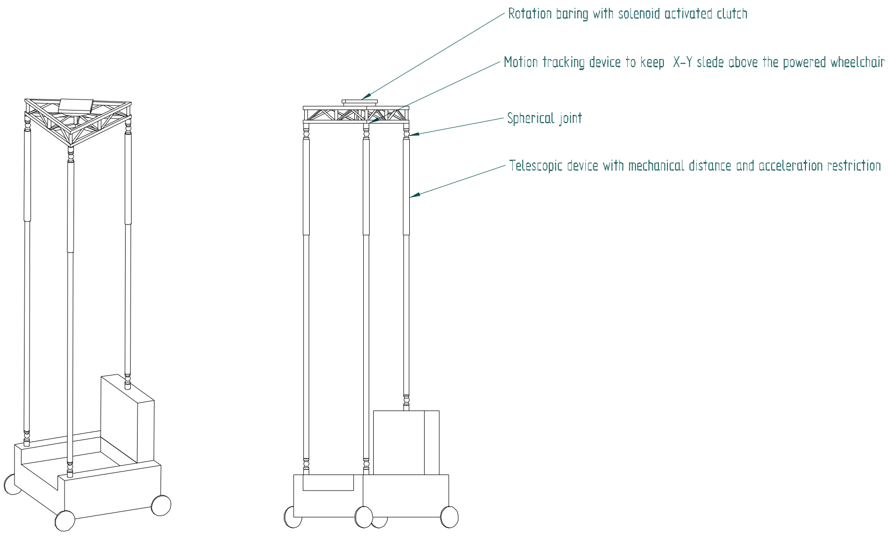

Figure 5.2: Design G

Appendix A

Requirements

A.1 General operations

- The powered wheelchair safety support shall provide individual protection to maximum 2 human subjects.
- Before each simulation session, a test person shall inspect and test the powered wheelchair safety support real time to verify that the system is working correctly and that there is enough clearance to walls or objects. A redundant lifeline should be used for the tester.
- Before each simulation session, all equipment on the platform must be checked whether they are properly placed and tethered. This shall be prompted by the control computer and confirmed by the operator.
- When the powered wheelchair safety support intervenes, an indication light or sound shall be visible or audible both in the simulator and in the control room.
- The researchers on the platform and the operator in the control room shall be trained or instructed on how to use the powered wheelchair safety support.
- The powered wheelchair safety support shall not block the (emergency) exit.
- After a power failure, emergency lights must make it possible for the subjects to find their way outside the simulator. The powered wheelchair safety support should only be released (manually) when the motion platform is completely settled.
- The powered wheelchair safety support should have an independent motion tracking system to monitor wheelchair movement.
- Although platform tilts of maximum 15 degrees will be used, the hardware limitation of the platform is a tilt of 40 degrees. Therefore, the powered wheelchair safety support will be designed to be operated safely at rotations of the motion platform up to 40 degrees.
- Normal accelerations and decelerations of the motion platform will be maximum 1 g in translational directions. For extreme motion system failures (like sudden valve closure), the powered wheelchair safety support system should be designed to be operated safely to maximum decelerations of 2.5 g for about 350 ms. This number will be checked with the motion system supplier.
- The powered wheelchair safety support should be designed to be operated safely to velocities the motion platform of up to 1.5 m/s.

- It must be possible, either by the assistant or by an operator in the control room, to manually activate and reset the powered wheelchair safety support.
- When a subject in a wheelchair is connected to the powered wheelchair safety support, it must still be possible to connect him to medical equipment. Large medical equipment shall be tethered to the platform, preferably at the edge. Compact medical devices can be attached to the subject's harness.
- Connecting lines between the subject and medical equipment shall not interfere with the movements of the subjects.
- Regular maintenance shall be done by competent persons at TRI. Extensive maintenance should be done by mechanics with support or supplier/ manufacturer consult.
- The supplier or manufacturer of the powered wheelchair safety support shall provide documentation on how to maintain and check the powered wheelchair safety support.
- Defective components shall be replaced only by original parts or parts prescribed by or in consultation with the manufacturer.
- The mean time to repair (MTTR) of the powered wheelchair safety support shall be less than 4 hrs, depending on the broken component.
- The mean time between failures (MTBF) shall be more than 50.000 hrs. (This number is presumed for the time being until a further analysis has been made).
- Two persons should be able to do the maintenance on the powered wheelchair safety support.
- After each repair, a competent person shall test the powered wheelchair safety support real time to verify that the system is working correctly and that there is enough clearance to walls or objects. A redundant lifeline should be used for the tester.
- Different environments and surfaces may cause the platform and the powered wheelchair safety support to become dirty. The powered wheelchair safety support must therefore be easy to clean.

A.2 Manageability

- The powered wheelchair safety support will work in the CEAL simulator environment.
- Temperatures -10 ° C to + 40 ° C.
- 0-99 % relative humidity.
- Dry, Snow and or rain
- Adjustable wind velocity (ventilator)
- One subject in a powered wheelchair, and the powered wheelchair itself with a total mass of 300 kg
- The maximum weight of the powered wheelchair safety support shall not exceed 150 kg.
- The supervising second subject on the platform has a total mass of 150 kg.
- The powered wheelchair safety support should be large enough to be fitted on a lage range of powered wheelchair designs taken into account that some wheelchairs are still to be designed.
- The powered wheelchair safety support should be able to have a horizontal working area of 6000 mm in diameter.
- The powered wheelchair safety support should fit within the limits of the supporting structure of 3700 mm.

A.3 Use scenario specific

- The Platform can translate in all directions
- The platform can be placed in an fixed incline of 15°.
- The platform can be placed with slowly increasing incline to the maximum of 15°.
- The platform can be placed in an fixed incline of 5° when the ice/snow chamber is installed.
- Accelerations during normal motions are up to 10 m/s^2 in linear directions. For failure modes (sudden valve closure), accelerations can be as high as 2.5 g (although only for a small amount of time). [1].
- Disturbing movements at key moments, for example standing up out of the powered wheelchair or entering the platform.
- The subjects must be able to drive around freely in the wheelchair without being restrained by the powered wheelchair safety support. The powered wheelchair safety support should only intervene when the wheelchair reaches a the maximum angle and/or when the accelerations become to high.
- The subject shall not be disturbed by noise of the tracking system. Noise level of the tracking system should be about 30 dB maximum (library level). Above all, the subject shall not be able to perceive the operations of the tracking system by its noise.
- The subject must not be disturbed visually by the tracking system. The control room shall not be visible to the simulator occupants during experiments.

[1] Exact accelerations will be used in future calculations. This will be done in close consideration with the motion system supplier

- The planar range of the tracking system shall be an area of 6000 by 6000 mm. As an extra safety measure, only an area of 5000 by 5000 mm shall be used for experiments to create a buffer zone between subjects and the edge of the platform.
- The tracking system must be able to manage a vertical load of 450 kg (two subjects of 150 kg each and the powered wheelchair safety support).
- The tracking system must be able to manage a horizontal load of 600 kg (one subject of 150 kg walking, one subject in a powered wheelchair with a total mass of 300 kg and the mass of the powered wheelchair safety support 150 kg).
- The tracking system shall not drift away due to gravity or inertia effects. The suspension point of the powered wheelchair safety support must remain above the subjects within a reasonably range (about 0.5 m) when the motion platform tilts (up to 40 degrees) or translates (with maximum decelerations of 2.5 g).
- The maximum horizontal deviation due to a tracking error of the guidance mechanism shall be less than 100 mm.
- When subjects are moving too fast in horizontal direction and/or the tracking system is not capable of tracking them, the tracking system shall brake and as a response the powered wheelchair safety support shall hold the powered wheelchair.
- The tracking system shall be self-locking. It will be locked by brakes when no power is supplied to the drive system. Only when the drives system is powered, the brakes shall release.
- The maximum vertical deflection of the anchorage point of the subject shall be less than 22 mm when a force of 2943 N (300 kg) is applied (equivalent stiffness 130 kN/m).
- The maximum horizontal deflection of the anchorage point of the subject shall be less than 22 mm when a force of 4415 N (450 kg) is applied (equivalent stiffness 200 kN/m).
- The maximum height of the supporting structure of the powered wheelchair safety support on clean platforms is 3990 mm from the platform surface. Dimensions for specific research pallets are different (see chapter 10).
- The supporting structure of the powered wheelchair safety support on clean platforms shall measure at maximum 6000 by 6000 mm. Dimensions for specific research pallets are different.
- The supporting structure shall be able to manage the load of the subjects and assertive devices plus the load of the tracking system, powered wheelchair safety support system and the roof structure.
- Wheelchairs and assertive devices shall be attached to the powered wheelchair safety support system independent of the subject. When the subject is arrested, the load of the wheelchair and assertive devices should not be transmitted to the supporting structure through the subject. The subject is strapped in the wheelchair.
- Wheelchairs or assertive devices should be structurally capable to cope with the forces involved during an intervention of the powered wheelchair safety support. Decelerations are up to 1 g for normal motions and can be as high as 2.5 g during motion system failures. This will be checked with the motion system supplier. TRI is responsible to make sure that prototypes can cope with these decelerations.
- When a subject is driving a powered wheelchair, the wheelchair shall brake automatically when the powered wheelchair safety support intervenes. This to prevent the wheelchair from moving further while the subject is being arrested.

- In the case of a failure of the powered wheelchair safety support, assertive devices like powered wheelchairs must be stopped as well.
- The powered wheelchair shall be connected to the powered wheelchair safety support by a rigid construction. To brake the powered wheelchair, the rigid construction might need to press down the wheelchair to the platform with a force of about 900 N and using braking pads.
- The subject in the wheelchair and the assistant will be allowed to move over the platform within an area of 6000 by 6000 mm. Vertical movements of the wheelchair from the platform are most likely uncommon.
- The powered wheelchair should be driven over the platform at a maximum speed of about 1.5 m/s. This velocity should be restricted and this should be made sure for every powered wheelchair before it will be used for experiments.

A.4 Research pallets specific

- The planar range of the powered wheelchair safety support in the ice chamber should an area 6000 by 6000 mm. As an extra safety measure, only an area of 5000 by 5000 mm shall be used for experiments to create a buffer zone between powered wheelchair safety support and the wall of the ice chamber.
- There will be no dynamic testing when the ice chamber is installed the platform can have a maximal fixed incline of 5°.
- For some experiments, larger cabins are used. These can be living rooms, bathrooms or even subway sections. The powered wheelchair safety support should be able to be used when entering these cabins without being obstructed by doorways and roofs.
- The powered wheelchair safety support must be relatively immune to or protected from dirt, dust, snow and water.
- Any optical tracking system shall be insensitive to condensation, or appropriate means shall be taken to eliminate inaccuracy or failure due to condensation.
- The required obstacles on the research pallets are:
  - 10-18 cm curbs
  - Snow powder/packed/slush
  - Mud/bare ground/sand
  - Wet surface
  - Ice(solid)
  - Asphalt
  - Uneven terrain
  - Potholes

A.5 Failure modes

- When malfunctions are recognized in the motion system, the tracking system should brake. Even when no abnormal platform movements occur. This can only be triggered by a signal send by a computer or manually by the operator.

- The tracking system should brake and the powered wheelchair safety support should remain functional whenever abnormal platform movements at high accelerations occur. This would be the case when a motion system failure has not been recognized in time or at all (failure alert not send by computer or by operator).
- Measures through redundant systems shall be taken to limit extreme platform movements. The powered wheelchair safety support however should be functional even when these redundant systems fail.
- The powered wheelchair safety support should remain functional when the tracking system fails. Experiments should be stopped however until the tracking system is operational again.
- Before the experiment starts, TRI researchers shall make sure no object or obstacle can be reached when a test person sways sideways due to a sudden stop of the motion base. The powered wheelchair safety support prevents contact with the sidewalls but cannot prevent currently unforeseen contact with high obstacles. For this reason this is TRI's responsibility.

Bibliography

[1] Prof. Dr. Ir. H.H van den Kronenberg , F.J. Siers *Methodisch ontwerpen Ontwerpmethoden, voorbeelden, cases, oefeningen.* ©1998 Educative Partners Nederland BV, Houten. ISBN: 90-11-04529-7.