SnowGo

DESIGN AND PRELIMINARY TESTING OF A NOVEL SIT-SNOWBOARD, ENABLING CHAIRLIFT USAGE

M.R. Hoogwout
Design and preliminary testing of a novel sit-snowboard, enabling chairlift usage

by:
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TU Delft
today isn’t just another day. today I’ll create something beautiful.
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DESIGN AND PRELIMINARY TESTING OF A NOVEL SIT-SNOWBOARD ENABLING CHAIRLIFT USAGE

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ABSTRACT
Sit-snowboards allow a person with the inability to actively use his/her legs to snowboard while sitting. However, existing prototypes do not allow using a chairlift. The goal of this study was to modify a prototype sit-snowboard, MINI, to add chairlift accessibility. MINI has a seat construction and two handlebars which allow the user to steer the snowboard. After thorough assessment of all constructed design parameters the most important design parameters for this research were determined; 1) the sit-snowboard seat needs to turn 90 degrees with respect to the snowboard, 2) the tubes of the sitting construction have to be constructed differently to allow the chairlift seat to get under the sit-snowboard seat, and 3) the rear handlebar needs to make way to allow space for the chairlift. A redesign of MINI was made with a bearing and locking mechanism for the sit-snowboard seat and detachable handlebars with a locking mechanism. Subsequently the prototype, SnowGo, was built and tested on snowboard-functionality and chairlift accessibility. The test results show that with SnowGo, it is possible to use the chairlift and maintain the ability to sit-snowboard. Using the chairlift without tumbling over during loading and unloading requires practice, but the sit-snowboarder showed that he did not need a lot of practice with SnowGo since he was able to use the chairlift without falling in four out of five trials. Two advantages were that the safety-bar of the chairlift can be closed during the chairlift ride and that the chairlift can be used by the sit-snowboarder completely independent of any help from a second person.

Keywords: Disability, snowboard, sit-snowboard, design, paraplegia, accessibility

1. INTRODUCTION
Snowboarding is an extreme sport that seems to have more injuries than downhill skiing \cite{Bladin, 2004, Prall, 1995, Fulham ONeill, 1999, Seino, 2001, Chow, 1996}. In a study of 7188 injuries caused by snowboarding, 3.3 percent were spinal cord related, compared to only 1.4 percent of spinal cord injuries found with skiing \cite{Yamakawa, 2001}. Of all spinal cord injuries, 60 percent results in paraplegia. With a wheelchair paraplegics can participate in activities of daily living and with specially designed wheelchairs participation in sports is possible \cite{Princess Alexandria Hospital’s Spinal Injuries Unit, 2012, Anastasia, 2011, Nasuti, 2010}. However, until recently, there were no aids to help paraplegics to snowboard (App. 1). The current work focuses on improving and testing such an aid, a sit-snowboard.

1.1. Background
1.1.1. Snowboarding
Figure 1 displays a drawing of a regular snowboard. A rider of this snowboard is called a snowboarder and he/she is snowboarding. A snowboard has a toe side edge and a heel side edge, and a nose end and a tail end (Fig. 1). While descending a slope, the downhill edge of the snowboard is the leading edge, which optimally is the edge that is not engaged in the snow. The edge engaged in the snow is the uphill trailing edge. When the leading edge does engage in the snow the snowboarder ‘catches an edge,’ causing the snowboarder to trip (App. 15) \cite{mechanics of sport, 2013, Real
world physics problems, 2009][Snowboard Tuning, 2013]. While snowboarding it is possible for the user to make a turn, or skid. When making a turn the user switches the leading edge from the heel side edge to the toe side edge or vice versa. Toe side and heel side turns are made while leaning on the toe side edge or heel side edge of the snowboard, respectively. The snowboarder should shift his/her weight to the toe or heel side edge of the snowboard to engage that edge in the snow. The nose and tail of the snowboard are wider than its waist, creating a curve on the edge of the snowboard (Fig. 1) [Mechanics of sport, 2013] [Real world physics problems, 2009][Daugherty, 2013]. When a toe or heel side edge is engaged in the snow, a turn can be performed along this curved edge of the snowboard. When the user is skidding, the snowboard moves down the slope in a sideways manner (using the long edge of the snowboard) whilst keeping the leading edge on one edge either the heel side edge or toe side edge. Adjusting the angle between the snowboard and the snow controls the skidding speed. A larger angle equals less speed whilst a smaller angle provides more speed.

A snowboarder is connected to the snowboard with snowboarding boots by strapping them to the snowboard with bindings. Figure 1 shows the placement of the bindings, these are indicated by the foot prints.

1.1.2. MINI

MINI (Fig.2) is a prototype of a sit-snowboard (Prodaptive, Den Haag, The Netherlands) (App. 2). MINI has a seat construction consisting of a seat, kneepads, and foot straps. The seat construction ensures the sit-snowboarding position. A pair of handlebars and limiters allows the user to transfer snowboard controlling forces to the snowboard. In regular snowboarding, the snowboard controlling forces are transferred from the user to the snowboard through the boots that are attached to the snowboard. In previous evaluations, three people with a disability (two people with Spina Bifida, one with Spastic Quadriplegia due to cerebral palsy) readily learned to sit-snowboard using MINI. However, a major drawback when using MINI is that the sit-snowboarder cannot use a chairlift. In order to use a chairlift, the snowboard should be pointing longitudinally in the direction of the chairlift motion but in that position, MINI cannot be placed on a chairlift seat.

The aim of this study is to redesign MINI to allow for chairlift use, while maintaining MINI's snowboarding performance (App. 11, 14).

2. METHOD

2.1. Conceptual design

2.1.1. User

The target user-group of MINI and therefore for this project consists of people who still have their legs but have difficulties or are unable to use them. The user must have control over his/her core muscles, pelvic muscles, and arm muscles to use the sit-snowboard (App. 3). People with Cerebral Palsy, Multiple Sclerosis
(a.k.a. MS), Amyotrofe Lateral Sclerosis (a.k.a. ALS), dystrophy, and spinal cord conditions, but also people with weak muscles or joint aches can benefit from using the sit-snowboard instead of a regular snowboard. A user with no active muscle function in the legs (but full control of trunk stability and arm muscles) was taken as a worst-case scenario on which the design was based. An example of such a user is a paraplegic with an L2 lesion.

In order to understand the target user-group a questionnaire was conducted among 20 target users, and an interview was held with a sit-skier, a snowboarder, and an adaptive snowboard instructor. The results suggest that users want to be in control, and the product should be easy to use (App. 4-9). Asking for help is not a problem for target users as long as often-recurring maneuvers can be performed as independently as possible.

2.1.2. Snowboarding functionality

To ensure that the snowboard functionality is maintained in the redesign, the forces and moments during snowboarding were analyzed to set design requirements.

During sit-snowboarding, the sit-snowboarder must be able to tilt and twist the snowboard and actively influence the force on the heel or toe edge of the snowboard by moving the user's center of mass (COM). A sit-snowboarder uses the hand and arm muscles to operate the handlebars and apply a tilting moment or a torsional moment to the snowboard (Fig. 3A, 3B, and App. 11). The tilting moment is used to control the angle between the snowboard and the snow which is used to control the skidding speed. The torsional moment is used to twist the snowboard which is used to initiate a turn. During a turn, a sit-snowboarder has to actively balance the centrifugal force ($F_c$) with the gravitational force ($F_g$) to refrain the snowboard from drifting (Fig. 3B). Following references the balancing force can be generated by moving the COM over the trailing edge [Davis, 2010][mechanics of sport, 2013][Bomber, 2014]. The sit-snowboarder can control the position of the COM with so-called limiters. They form the connection from the seat construction to the snowboard (Fig. 2, App. 11). The limiters are constructed out of two folded aluminum sheets with a piece of rubber in between. The rubbers in the limiters give the sit-snowboarder the ability to tilt the COM from heel side to toe side in a controlled manner, whilst applying a moment to the snowboard. The placement of the COM above the limiter determines the amount of tilt of the limiter which in turn determines the moment on the snowboard (Fig. 3C).

Based on the afore described snowboarding characteristics and the wish to maintain the snowboarding performance of MINI, the following design choices were made: the position of the seat, kneepads, and foot straps were maintained in the redesign. The
redesigned sit-snowboard has to fit onto a regular snowboard to allow the sit-snowboarder to choose any preferred snowboard (App. 10). The sideways position on a snowboard during sit-snowboarding should be maintained in a redesign to allow for using similar snowboarding techniques as with regular snowboarding (App. 11). The redesign should maintain the ability to twist the snowboard (max. 10 degrees), as far as the handlebars allow. The redesign must also be able to move the COM from heel- to toe-side over the total width of the snowboard (270 mm (App. 18)), as far as the limiters allow. For the sit-snowboarder to have control over the position of the COM, the weight of the redesign should not exceed 20 kg (App. 18). The distance between the bottom of the board and the sitting tube (Fig. 2) of the redesign should be 665 mm or less when riding the snowboard. In combination with MINI’s seat, a higher sitting tube height makes the sit-snowboarder insecure/afraid to lose balance (App. 2,5).

2.1.3. Chairlift use

A snowboarder will usually go up a slope by means of a chairlift. A chairlift consists of several chairs (Fig. 4) attached to a moving cable that is suspended above the ground by pillars, loading stations, and unloading stations. A chair consists of two to eight chairlift seats, depending on the type of chairlift.

Generally, a chairlift ride has three phases: 1) the loading phase, 2) the riding phase, 3) the unloading phase (Fig. 4, App. 14). During the loading phase, the sit-snowboarder has to propel him/her-self to get to the loading area. The sit-snowboarder waits at the loading area and takes a seat onto the chairlift seat when the chair is close enough. The sit-snowboard has to be accelerated to the same speed as the chairlift ($V_{lift}$). During the riding phase, the snowboarder should remain in the chairlift seat and should maintain balanced by keeping the COM above the chairlift chair. During the unloading phase, the sit-snowboard must be detached from or lifted off the chairlift chair. After unloading, the sit-snowboard must be decelerated and come to a stop without catching an edge, on a downward slope with a chosen maximum angle of 15 degrees based on the slope angle of Snowworld with a safety factor of 3 (App. 12).

To avoid catching an edge during the loading and unloading phase the snowboard needs to be close to parallel with the line of motion of the chairlift (Fig. 4). The ‘angle of exit’ ($\beta_{exit}$) is set as the angle of deviation of the snowboard from this line of motion. A simplified model of the sit-snowboard is created to determine the maximum allowable, safe angle of exit of the snowboard during unloading of the chairlift (Fig. 5, 6, and App. 17). The sit-snowboarder is modeled to catch an edge at unloading of the chairlift. In this model the sit-snowboarder and the snowboard are considered as one rigid body, modeled as an inverted pendulum, with the COM placed at a height of 0.62 m (z) from the bottom of the snowboard. The snowboard is modeled parallel with the slope ($\alpha_z$) at the point of unloading (Fig. 5, 6). When the sit-snowboarder catches an edge the sit-snowboarder is modeled to pivot around the edge of the snowboard ($A$). During this pivoting motion the COM of the sit-snowboarder including the sit-snowboard will go from an initial height ($h_1$) to a maximum final height ($h_2$). If the motion continues beyond the final position (Fig. 5) the COM goes beyond the edge of the snowboard and the sit-snowboarder will tumble. To make sure that the sit-snowboarder will not tumble, the kinetic energy ($E_k$) that the sit-snowboarder and sit-snowboard possess at the start of the pivoting motion has to be equal to, or less than the
amount of potential energy \((E_2)\) that can be obtained with the height gain \((dh)\) (Eq. 1, Fig. 5).

\[ \sum E_1 = \sum E_2 \Rightarrow h_2 - h_1 = \frac{0.5V_{lift}^2}{g} \quad [\text{Eq. 1}] \]

\[ h_x = (z + L \cdot \tan(\alpha_x)) \cdot \cos(\alpha_x) \quad [\text{Eq. 2}] \]

\[ \alpha_2 = \tan^{-1} \left( \frac{L}{z} \right) \quad [\text{Eq. 3}] \]

Where \(L\) is the distance (parallel with the line of motion), measured from the origin \((O)\) of the snowboard to the edge of the snowboard (Fig. 6). \(g\) is the gravitational acceleration. Distance \(L\) is directly related to the angle of exit (Eq. 4).

\[ \beta_{exit} = \sin^{-1} \left( \frac{0.13}{L} \right) \quad [\text{Eq. 4}] \]

For a slope angle of 15 degrees and a maximum chairlift speed of 9 km/h, the angle of exit should be between -8 and 8 degrees when unloading the chairlift (Fig. 4, App. 17). If the slope angle is greater than 15 degrees, the speed higher than 9 km/h, or when the COM is placed higher than 0.62 m, the angle of exit must be smaller to avoid tumbling.

Based on the user-group preferences and the chairlift phases it was decided that the sit-snowboarder should 'sit' on a chairlift chair during the chairlift riding phase with the redesign. This was mainly based on social and safety reasons (App. 9, 19). The redesign should allow the sit-snowboarder to stay in the sit-snowboard seat at all times to save time and effort. A chairlift has a sitting height of 480-540 mm, a minimum sitting depth of 460 mm and a tilt angle of 0-15 degrees [Passenger Ropeways, 2011] (Fig. 7). To allow room for the chairlift chair to get under the seat of the redesigned sit-snowboard, a 350 mm space (clear space) should be kept free from any type of construction (Fig. 7, App. 22). Based on chairlift data from ski areas (App. 13) it is determined that the redesign should cover no more than two chairlift seats (max. width of 940 mm) since 66% of the chairlifts are three to six person chairlifts and MINI is designed to be used with an abled instructor accompanying the sit-snowboarder.
2.2. Design

Due to the preconditions and design criteria, it was chosen (App. 18, 19) to have two use modes on the redesigned sit-snowboard: 1) a snowboarding mode to allow a sideways position during sit-snowboarding, and 2) a chairlift mode to point the snowboard longitudinally in the direction of the chairlift motion (Fig. 8). The sit-snowboarder will have to switch from one use mode to the other before loading and after unloading the chairlift.

To enable switching between the two use modes, three main design decisions were made; 1) the sit-snowboard seat should be able to turn 90 degrees with respect to the snowboard, 2) the tubes of the sitting construction have to be constructed differently to allow the chairlift seat to get under the sit-snowboard seat (clear space, Fig. 7), and 3) the tail side handlebar has to be moved out of the way in the chairlift mode to allow space for the chairlift (clear space, Fig. 7).

2.2.1. Seat

To change between the snowboarding mode and the chairlift mode a center rotation of the seat is chosen as it allows changing the modes of the sit-snowboarder without shifting the COM beyond the edges of the snowboard. The center rotation also helps keeping balance and stability in and between both modes (Fig. 8) without the need for extra equipment.

Since rotating the seat should be voluntarily only, it is important to be able to securely lock the rotating mechanism whenever the user does not intend to rotate. Such a locking mechanism has to withstand a torque of 669 Nm, which is generated by the arm forces on the handlebars when a turn is initiated (App. 11). The mechanism should allow to be locked in two positions and should require no more than four actions to lock and unlock the mechanism. A locking pin was chosen as the mechanism to lock the seat. The pin runs through the two sitting construction in between the legs of the user and is connected to a flange which is welded onto the vertical tube of the sitting construction (Fig. 9). The pin is pushed down by a spring and can be pulled up by the user which will unlock the mechanism. When unlocked the sitting construction allows the entire construction (minus the vertical tube) to be turned into the other mode.

A Microsoft Excel 2010 model was made to verify the body position of the sit-snowboarder needed to keep the COM on the chairlift seat during the riding phase. In this model the COM of the different body parts (feet, lower legs, upper legs, torso, hands, lower arms, upper arms, head) of the sit-snowboarder are combined to check the placement of the COM of the whole body (App. 16, 22) [Clauser, 1969] [Voskamp, 2004]. Assuming that the COM should stay 100 mm behind the middle of the snowboard (with the arms of the user folded alongside the torso) the user should keep the upper body maximally tilted 5 degrees forward (Fig. 10), according to this model.
2.2.2. Sitting construction

Since it is decided to place the sit-snowboard seat on the chairlift chair the sitting construction has to be built so that the chairlift chair fits under the sit-snowboard seat. The new design (Fig. 9) allows the user to rotate his/her entire body position with the sitting construction and allows the bearing to be at the top of the construction. The placement of the bearing at the top of the construction, as opposed to at the bottom, results in lower moments on the bearing and thus a smaller bearing. This particular design of the sitting construction allows the construction to be bended out of two pieces of (6061 Aluminum alloy tube, outer diameter 30 mm wall thickness 5 mm), which requires a minimal amount of welds. The sitting construction has to withstand the forces listed in Table 1 (and in App. 20, 23).

<table>
<thead>
<tr>
<th>Direction</th>
<th>Force [N]</th>
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<tr>
<td>x</td>
<td>$F_{slope} = 589$</td>
</tr>
<tr>
<td>y</td>
<td>$F_{fall} = 2355$</td>
</tr>
<tr>
<td>z</td>
<td>$F_{bump} = 1178$</td>
</tr>
</tbody>
</table>

Table 1 – Forces and moments, as calculated, on the sitting construction

The computer aided design (C.A.D.) tool Solidworks (corp. Solidworks 2013 education edition x64Solidworks) was used to verify that the mathematical complex sitting construction will not plastically deform during use. Since Solidworks SimulationXpress does not allow a simulation with more than one part only half of the frame could be simulated at once. Applying the maximum force of 2355 N ($F_{fall}$) on the sitting construction results in the Von Mises stresses as displayed in Figure 11. These stresses stay below the yield strength of the 6061 Aluminum alloy (275000 MPa), which means that the sitting construction will not bend or break with the simulated maximum loading.

2.2.3. Handlebar

It is decided to let the tail side handlebar make way for the chairlift by taking the handlebars off the snowboard (App. 19). Removing both handlebars off the snowboard (Fig. 12) also provides the sit-snowboarder with a means for propulsion in the chairlift mode, much like ski poles, and a method to maintain balance during loading and unloading of the chairlift, much like a sit-skier uses his/her outriggers (App. 19). A further benefit is that the handlebars can be used as an aid to recover after a fall.
The locking mechanism of the handlebar has to withstand the forces and moments listed in Table 2 (and App. 20, 25).

<table>
<thead>
<tr>
<th>Direction</th>
<th>Force [N]</th>
<th>Moment [Nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>$F_{hand} = 1013$</td>
<td>949</td>
</tr>
<tr>
<td>y</td>
<td>$F_{fall} = 2355$</td>
<td>949</td>
</tr>
<tr>
<td>z</td>
<td>$F_{hand} = 1013$</td>
<td>471</td>
</tr>
</tbody>
</table>

Table 2 – Forces and moments, as calculated, on the handlebar locking mechanism

It was chosen to use a mechanism similar to mechanisms found in crutches (App. 25). The mechanism is operated by a bicycle brake grip, from which a cable runs to the mechanism shown in Figure 14. In the locked position the two pins are pushed outward by a spring. When the sit-snowboarder squeezes the brake handle the pins are retracted and the mechanism is unlocked. In the unlocked position the upper part of the handlebar can be retracted from the lower part of the handlebar (Fig. 12). To make this mechanism user friendly the maximum gripping force used to operate the brake handle was set at 115 N, this is half of the maximum gripping force of a p5 young adult (20-30 years of age) [DINED, 2013] (App. 25). The maximum operating time (time to unlock and lock the mechanism) was set at two minutes. This amount of time is similar to the time needed for snowboarders to get ready strapping their boots onto the snowboard, and stays within the time a potential user wants to spend before asking for help (App. 9).

Since Solidworks cannot successfully calculate the forces in all the connections and assembled parts of the new design, a prototype, called SnowGo, was built to test the feasibility of the selected design ideas (Fig. 13). The tubes in the construction are made out of aluminum.
6061 alloy. The limiter plate, needed to connect the entire sitting construction to the snowboard, is made of plywood coated with carbon fiber and epoxy. The locking pins in both the handlebars and the seat are made out of stainless steel. The insert and handlebar bearing are made out of PVC, the spring is a leaf spring, the rope used inside the insert is Dyneema Purity fiber rope (according to DSM lower friction, higher strength, and less elongating than brake wire [DSM, 2014]), and the cable that runs up to the brake handle is a bicycle brake cable (App. 25). A cross section of the seat bearing can be seen in Figure 14. The tubes of the sitting construction, the vertical tube, the connecting bus, the connection plates, and the bearing house are made out of Aluminum 6061 alloy. The top bearing and flange bearing are made out of POM, which is a wear-resistant material for cold conditions. The rest of the construction is form fitted (App. 26, 27).

2.4. Tests
2.4.1. Lab test
Twelve volunteers, eight male and four female, participated in lab tests to test the snowboard ability of SnowGo in a controlled environment. All subjects were between 20 and 26 years old, were between 1.63 and 1.91 m in height, and had 0-95 days of snowboarding experience. None of them had any conditions that negatively affect the upper or lower extremities. All subjects were informed on the aims of the research and signed a written consent prior to participation. Three main tests were performed during the lab test (App. 31):
1) The falling test: The ability of changing the position of the COM largely determines sit-snowboard performance. This ability was tested by requesting the subjects to move the COM to heel or toe side in 3-5 seconds while using SnowGo. If the subjects could tumble onto their buttocks or knees respectively SnowGo passed the test. The subjects were caught in their fall and additional safety measures were taken to facilitate a soft landing. One tumble was seen as one trial. This test existed out of eight trials, four heel side trials and four toe side trials. Out of the four trials two trials were performed with the hands on the handlebars and two trials were performed with the hands on the upper leg.
2) The handlebar test: This test was done to verify the time required to get the handlebars ‘chairlift ready’. SnowGo passed the test if the time needed stayed under one minute for one handlebar (section 2.2.3). The subjects were asked to take out the handlebar and put it back

Figure 14 – Cross section of the seat bearing.

Figure 15 – Chairlift test: (A) the subject was asked to move upper body forward until falling. \( \alpha \) was the tilt angle measured right before the subject fall, (B) back position with the buttocks all the way into the seat (positive tilt angle), (C) knee pad position with the knees firmly pressed into the knee pads (negative tilt angle)
3) The chairlift test: The projection of the COM of the construction including the user should stay on the chairlift (Fig. 19) when the sit-snowboarder takes on a vertical upper body position. The subjects were placed on a full-scale wooden model of a chairlift while sitting in SnowGo to determine the angular upper body position at which the subject tumble out of the chairlift without safety bars. Then the subjects were asked to tilt their body forward in 3-5 seconds up to the position at which the subject ‘falls off of the chairlift’. All trials were recorded with a camera, creating 24 frames per second. A frame of the moment just before the snowboard started tilting was put in Photoshop (Adobe Photoshop CS5.1 (64 Bt)) and the Ruler tool was used to measure the angle between the vertical and the upper body (Fig. 15A, App. 31). In two trials the subjects were sitting with their buttock back into the seat (Fig. 15B) and in two trials the subjects were sitting with their knees in the kneepads (Fig. 15C). The Shapiro-Wilk and the Kolmogorov-Smirnov tests were used to verify the normal distribution of the data. A two-tailed paired t-test was performed (IBM SPSS Statistics version 23) to check the inter subject dependence of the angle of the upper body between the results gathered from the two different sitting positions.

2.4.2. Field test: Sit-snowboarding

To test the sit-snowboarding performance a test was conducted with two subjects using both MINI and SnowGo. The first subject was a 25-year-old male, with a height of 1.86 m and a weight of 80kg with 25 accumulative days of snowboarding experience. The second subject was a 20-year-old female, with a height of 1.72 m and a weight of 58 kg with 30 accumulative days of snowboarding experience. Both subjects were informed on the tasks of the research and signed a written consent prior to participation. During the test the subjects would go through a learning cycle with MINI and SnowGo at the indoor ski slope facility Snowworld Zoetermeer, The Netherlands. The male started with MINI and continued with SnowGo and the female used the two prototypes in the reversed order. Two main tasks were performed (App. 33):

1) Falling leaf heel and toe side (Fig. 16A), which implies that sit-snowboarder stays on either the heel or the toe side edge and will skid down the slope traversing from left to right and vice versa following a path (Fig. 16A). Each traverse switch needs to be made between the right and the left side cones subsequently. This process is repeated until the bottom cones have been reached. To compare the performance of the sit-snowboarder on SnowGo with his/her performance on MINI the amount of traverse switches made were counted. SnowGo passed the test if the sit-snowboarder could make the same amount or more traverse switches compared to MINI in a set area (Fig. 16A). This test consisted out of six trials per prototype, three on the heel side edge and three on the toe side edge. First one training trial was performed to get familiar with the procedure and prototype. Subsequently two trials were performed in which the number of traverse switches was recorded.

2) Initiate heel and toe side turns (Fig. 16B). In this test the subjects would sit-snowboard straight down the slope until the initiation cone is reached. Once the cone was reached the sit-snowboarder would initiate a turn and try to end as close to the target cone as possible. Indicators used to compare the performance of MINI with SnowGo in this test is the deviation from the ‘perfect’ turn line (p) which is a quarter of an oval from the initiation cone to the target cone and the deviation from the target cone (c). This test consisted out of four trials per prototype, two on the heel side edge and two on the toe side edge. In all trials p and c were recorded.

2.4.3. Field test: Chairlift

The chairlift usage test was done at the indoor ski slope facility Snowworld Landgraaf to determine the chairlift abilities of SnowGo (App. 34). A 28 year old male, with a height of 1.76 m and a weight of 95 kg was used for this test. This test subject has Spina Bifida and had 10 accumulative days of sit-snowboarding experience prior to the test. The subject was informed on the aims of the research and signed a written consent prior to participation.
The test subject got into SnowGo to get onto the chairlift, ride to the top, disembark from the chairlift and come down sit-snowboarding.

This process was repeated 5 times, 2 times with an instructor and 3 times without an instructor. Since it requires practice to perform these maneuvers without falling, SnowGo passed the test if at least two sessions of loading and unloading the chairlift were performed without falling (App. 35).

Figure 16 – Test set ups; A) Falling leaf, the numbers display the number of traverse switches, B) initiating a turn, c is the distance to the cone and p is the distance to a perfect turning line. The circles displayed are cones.

### 3. RESULTS

#### 3.1. Lab test: Subjects

Each of the 12 subjects was able to fall forward and backward with SnowGo in the falling test.

During the handlebar test the subjects needed an average of 2.6 seconds (st. dev. 1.04 sec.) to take one of the upper parts of the handlebars out of the lower part of the handlebar, and an average of 3.5 seconds (st. dev. 1.82 sec.) to place one handlebar back onto the snowboard. All test subjects perform the maneuvers within one minute.

During the chairlift test the test subjects could tilt their upper body forward 1-23 degrees with an average of 12.3 degrees (st. dev. 5.4 degrees) (Table 3, Fig. 15B) before tipping over when they sit back into the sit-snowboard seat. When the subjects sit with their knees in the kneepads (Fig. 15C) four people could lean forward 4.5-14.5 degrees before tipping over. All the other test subjects had to stay tilted backward 1-13 degrees to refrain from tipping over (Table 3). The overall average of the upper body angle in knee pad position was 0.4 degrees (st. dev. 8 degrees) tilted backward. The angle of the upper body was significant (p = 0.0004) smaller when the subject would sit with his/her knees in the kneepads as compared to sitting with the buttock back into the seat.

#### Table 3 – Tilt angle of the upper body in the chairlift measured from a vertical position in degrees, Figure 16 (negative is backward, positive is forward)

<table>
<thead>
<tr>
<th>Test no.</th>
<th>Heel-side</th>
<th>Toe-side</th>
<th>Heel-side</th>
<th>Toe-side</th>
</tr>
</thead>
<tbody>
<tr>
<td>MINI 1</td>
<td>Subject 1</td>
<td>2</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>MINI 2</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>SnowGo 1</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>SnowGo 2</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>

#### Table 4 – Number of traverse switches with the falling leaf

<table>
<thead>
<tr>
<th>Test no.</th>
<th>Heel-side</th>
<th>Toe-side</th>
<th>Heel-side</th>
<th>Toe-side</th>
</tr>
</thead>
<tbody>
<tr>
<td>MINI 1</td>
<td>270</td>
<td>70</td>
<td>210</td>
<td>370</td>
</tr>
<tr>
<td>MINI 2</td>
<td>176</td>
<td>130</td>
<td>270</td>
<td>360</td>
</tr>
<tr>
<td>SnowGo 1</td>
<td>390</td>
<td>390</td>
<td>270</td>
<td>200</td>
</tr>
<tr>
<td>SnowGo 2</td>
<td>120</td>
<td>120</td>
<td>150</td>
<td>150</td>
</tr>
</tbody>
</table>

#### Table 5 – Deviation from the target; c is the deviation from the target pawn and p is the deviation from the ‘perfect’ turn line

The number of traverse switches with the falling leaf test can be found in Table 4. Table 5 shows the deviation from the ‘perfect’ turn line (p) and the deviation from the target cone (c) measured in the turn initiation test. MINI 1 represents the first test done with MINI and MINI 2 represents the second test done with MINI, the same goes for SnowGo 1 and SnowGo 2. A visual representation of these numbers can be found in Figure 17.
3.4. Field test: Chairlift

During the tests with the chairlift four out of five trials were completed without falling. These tests have shown that the safety bar can be closed during the chairlift ride, the chairlift did not have to be slowed down during loading and unloading of the chairlift, the prototype fits through the chairlift gates, and SnowGo only takes up one seat in the chairlift chair (Fig. 18, App. 35).

Figure 18 – The sit-snowboarder is unloading from a chairlift with SnowGo

4. DISCUSSION

4.1. Tests

The overall results of the tests seem to show that SnowGo allows the sit-snowboarder to use a chairlift while SnowGo retains MINI’s snowboard functionality. The results of the lab tests seem to show that SnowGo allows the placement of the COM on both the heel and the toe side edge, which is needed to be able to snowboard [Davis, 2010][mechanics of sport, 2013][Bomber, 2014]. The test subjects are able to detach the handlebars in less than one minute per handlebar, which shows that the handlebars comply with the one minute design requirement. The sit-snowboarding test suggests that SnowGo performs similar or even better at sit-snowboarding than MINI does. Comparing the number of traverse switches with the falling leaf test it seems that the subjects make the same amount of turns or more using SnowGo as compared to MINI (Table 5). Comparing the turn initiations it seems that SnowGo allows the sit-snowboarder to end closer to the target than MINI does (Table 7, App. 35). Since turns are one of the standard snowboard maneuvers the results of this study seem to show that the sit-snowboard is functional [Minnoye, 2010][Subic, 2010]. The chairlift lab test shows that the sit-snowboarder can tilt his/her upper body forward further when sitting with the buttocks in the snowboard seat (Fig. 15B). To get into this position the sit-snowboarder should shift his/her buttocks back into the sit-snowboard seat during the chairlift mode. This repositioning of the body might be advantageous to the tissue perfusion (skin and muscle) of the sit-snowboarder.
[Sonenblum, 2011][Crawford, 2005][Stockton, 2008]. Further research should be performed towards the ideal sitting position for the sit-snowboarder for both the chairlift mode and the snowboarding mode [Andersson, 1975][Dainoff, 2012][Human Factors and Ergonomics Society, 2007].

The results of the chairlift test suggest that full chairlift-riding functionality can be achieved with SnowGo, without any help of a second person. This would make the sit-snowboarder independent of help, which is desired by the potential user group (App. 4, 5, 9) [Harding, 2010]. These chairlift tests also have shown that the COM stays on the chairlift seat during the riding phase and that the safety bar can be closed during the riding phase, this seems to make the chairlift ride safer. The fact that SnowGo only takes up one seat on the chairlift makes it possible for sit-snowboarders to ride the chairlift with their teacher or friends, which benefits the social side of the chairlift (App. 5, 9).

During the lab test with subjects, the subjects were placed on a full-scale model of a chairlift to measure the tilt angle of the upper body at the point of ‘falling’ out of the chairlift. The results of this test differ from the results gathered with the excel model. The excel model showed an upper body tilt angle of 5 degrees in the knee pad position whilst the test determined a range of -13 degrees to 14.5 degrees. The difference can possibly be explained by the COM of SnowGo which is not included in the excel model. During this test the tilt angle of the upper body also seemed to be influenced by three main factors:
1) Test subjects arch their backs when leaning forward, placing the COM closer to the subjects buttocks than when the subjects would lean forward with a flat back
2) The test subject’s appear to extend their hips when they are scared of falling. This makes the snowboard tilt even before the subject is actually falling.
3) The fit of the test subject inside the sit-snowboard construction. The test subjects who have longer upper legs seem to be able to lean forward further when sitting in the knee pad position (Fig. 15C) compared to the subjects who have smaller upper legs.

These three factors seem to disturb the assumed direct connection between the tilt angle of the upper body and the placement of the projection of the COM. The influence of these factors should be researched in more depth to find any possible significance.

The subjects used during the sit-snowboarding field test do not have a physical handicap, this gives them the advantage to use their legs during sit-snowboarding. The test subjects mentioned using their legs to put more pressure on the knee pads and get MINI onto its toe side. The current sit-snowboarding tests seem to show that SnowGo has a similar performance compared to MINI. However, since the subjects had an advantage of using their legs there is a chance that SnowGo performs better than MINI when a target user uses the sit-snowboard. To compare the sit-snowboard functioning of MINI and SnowGo, for the potential user group, further research should be conducted using subjects that are not able to use their legs. This can be done by limiting the use of the legs of healthy subjects or by conducting the tests with subjects who have no control over their legs.

Since this research only focuses on preliminary testing of the snowboard abilities and chairlift opportunities of SnowGo, a follow-up to this research should be performed to test the sit-snowboarding performance with more subjects and to test the chairlift possibilities with more chairlifts. This research should determine if the chairlift can be used safely and if the safety bar can be closed in all chairlift configurations (App. 12) [Smartt, 2009].

4.2 Design

During the tests the design has been subjected to multiple falls, which result in a complex mechanical loading of the design [Lanfranconi, 2012]. The seat bearing, seat bearing lock, and sitting construction worked as designed and have shown no deformation during use.

This particular design of the sitting construction, including the bearing and the lock, has shown potential for SnowGo to combine sit-snowboarding with an alternative type of sit-skiing. By placing SnowGo into the
chairlift mode while going down a slope a similar activity to sit skiing can be envisioned [Petrofsky, 2003][Langelier, 2013]. Further design efforts can turn this option into a new type of snow-sport, and creates the possibility to perform two types of snow-sports with one product.

The handlebar design including the locking mechanism has shown to work as designed. The handlebars have even shown to be a useful means of propulsion. However, as the design of the handlebars was not yet focused on the propulsion function, the handlebars are very heavy. Further design efforts should therefore be focused on the propulsion with the handlebars. Using outriggers instead of the current handlebars can be a potential inspiration for the propulsion method. A lighter (now 2.9 kg) and more ergonomic design of the upper part of the handlebars might also be more convenient and comfortable for the sit-snowboarder to use [Greenberg, 1977][Armstrong, 1989][Mital, 1992].

The weight of SnowGo, 25 kg, is beyond the set requirement of 20 kg. Even though the subjects did not complain about the functioning of SnowGo a lighter design would be more convenient during transportation. The forces that act on the design need to be measured and calculated to be able to more carefully determine the design’s dimensions, and possibly minimize the weight of the design. Research should be conducted to measure the forces on and in the design.

A design iteration should also be performed to look into adjustability of SnowGo’s seat to center distance, kneepads to seat distance, and foot strap to kneepads distance, in order to address to the needs of a wider range of users. The sit-snowboard will be a better option for ski-schools if it can be used by a wider range of users [Garneau, 2011]. In this design iteration a choice has to be made towards the cost of the prototype and the adjustability of the prototype [Garneau, 2012].

5. CONCLUSION

SnowGo has shown to allow a sit-snowboarder to use the chairlift and seem to have remained the sit-snowboarding functionality as provided by MINI. SnowGo allows for more than it was designed for: the safety bar can be closed during the chairlift ride, the chairlift does not have to be slowed down during loading and unloading of the chairlift, the prototype fits through the chairlift gates, SnowGo only takes up one seat in the chairlift chair, and all chairlift maneuvers can be performed without any help from a second person. SnowGo is a leap forward in the design of sit-snowboards, since it allows people that have to use a wheelchair in everyday life to fully participate in snowboarding as a sport.

ACKNOWLEDGEMENTS

Thanks to Snowworld Zoetermeer and Snowworld Landgraaf for making their facilities available for the field tests.

REFERENCES


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APPENDICES
Appendix 1
Market Analysis
In this Appendix an analysis of the current, march 2013, market in adaptive snowboarding can be found.

Adaptive snowboards, are snowboard that are designed to help people who have difficulty using a regular snowboard. This market analysis was focused on adaptive snowboard available for MINI’s intended users (App. 3). Adaptive snowboards can be found in various designs and the user can sit in various positions with the optional use of limbs.

![Figure 1.1 - An adaptive snowboard called the BASS snowboard. It has a rigid structure placed on the snowboard with a swing like seat](image1)

The BASS snowboard [1.1] (Fig. 1.1), is an adaptive snowboard intended for the same user group as MINI however this adaptive snowboard only allows this user group to snowboard with a guide/trainer. With the BASS snowboard the user is not in control. This control is strived for in the new to be designed sit-snowboard (App. 4, 9).

With the sit-board [1.2], the user will be sitting in a similar position as someone riding a sled (Fig. 1.2). The user will not be having a real snowboard posture nor will this adaptive snowboard cause the rider to feel like snowboarding (App. 5, 9). This product will therefore not fulfill the needs of the intended user (App. 3).

References


Appendix 2

Current Designs Prodaptive
In this Appendix the current prototypes of the company Prodaptive can be found, these prototypes are displayed and mentioned with their pro’s and con’s. These pro’s and con’s were determined based on the interviews taken from the adaptive snowboard instructor.

<table>
<thead>
<tr>
<th>Prototype</th>
<th>Pro’s</th>
<th>Con’s</th>
</tr>
</thead>
</table>
| **Figure 2.1 - Name: ZERO** | • Steering with hands  
• Moves with the body of the user  
• Supports the entire leg  
• Allows the user to move COM | • Sitting height is too high  
• Scary to fall  
• Knees are restricted from any motions that feels scary  
• Too basic  
• Kept falling apart |
| **Figure 2.2 - Name: ONE** | • Steering was great  
• Transmission of motions is direct | • Sitting height is too high |
| **Figure 2.3- Name: SPIN** | • Simple design  
• Super light | • Felt limiting with the knee pads so close and the design being so static  
• Handlebars too far off to the nose and tail of the snowboard, the user can only make the tips of the snowboard twist. Did not steer right  
• It is hard to get in and out of the sit-snowboard  
• There is hardly any support from the seat |
| Figure 2.4 - Name: Fiets 1 | - It allows for a little damping in the system  
- Rubbers allow for a gradual movement  
- Continues feedback, at both the hips and the knees  
- Rubbers force you back to a central midpoint |
| Figure 2.5 - Name: TIM | - High handlebars, which is easy for instructors  
- Can use you pelvic muscles to move nose to tail  |
| Figure 2.6 - Name: MAX | - Rollbar/rollcage  
- Actual seat  
- Nose/tail and toe/heel motions combined  |
| Figure 2.7 - Name: MINI | - Direct steering  
- Comfortable sitting height  
- Kneepads are comfortable  
- Light design  
- Robust  |
| | - Floppy feet  
- “floating” between toe-and heel-side  |
| | - Sitting height was too high  
- Very heavy, which make you feel like you are not in control  |
| | - Very heavy  
- Had to tighten the screws real good, would get out of alignment real quick  |
| | - Getting in and out of the design takes a lot of effort  
- Baseplate started to bend  
- Relatively complex and expensive to make  |
Based on the pro's and con's of the current prototypes design parameters were determined for the new to be designed sit-snowboard (App. 16). Even though MINI was not Prodaptive’s latest model this prototype was chosen as a starting point since it is the only product that is fully developed into a product which is readily available for consumers.

MINI is designed for guided use only, this guide will either be an instructor or a snowboard buddy. It is a beginners sit-snowboard which will not go faster than 30 km/h. The user has a maximum weight of 80 kg, and the dimensions of a p50 DINED person. The snowboard will only be used on well-groomed slopes which eliminates riding over big bumps and jumps, the maximum bump MINI will ride is 40 cm.
Appendix 3

Potential Users
In this Appendix information can be found on the potential users of a sit-snowboard design like MINI.

Earlier research in human kinetic technologies showed that the difference between snowboarding and sit-snowboarding can be seen in motions of the joints that need to be used. Table 3.1 and Figure 3.1, show the comparison between the joint motions and shows the minimal requirements of joint motions needed to be able to (sit-)snowboard.

<table>
<thead>
<tr>
<th>Joint Description</th>
<th>Regular snowboarding</th>
<th>Sit-snowboarding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Art. Talocalcaneonaviculare &amp; art. Talocuralis</td>
<td>Active</td>
<td>No motion</td>
</tr>
<tr>
<td>Pro/supinaatie (Fig. 3.1G)</td>
<td>Active</td>
<td>No motion</td>
</tr>
<tr>
<td>Plantair/dorsaalflexion (Fig. 3.1H)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Art. Genus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexion/extension (Fig. 3.1H)</td>
<td>Active</td>
<td>Passive</td>
</tr>
<tr>
<td>Art. Genus</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Endo-/exo-rotation (Fig. 3.1F)</td>
<td>Active</td>
<td>No motion</td>
</tr>
<tr>
<td>Art. Coxae</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ab-/adduction (Fig. 3.1D)</td>
<td>Active</td>
<td>Passive</td>
</tr>
<tr>
<td>Ante-/retro-flexion (Fig. 3.1E)</td>
<td>Active</td>
<td>Active</td>
</tr>
<tr>
<td>Exo-/endo-rotation (Fig. 3.1F)</td>
<td>Active</td>
<td>Passive</td>
</tr>
<tr>
<td>Art. Intervertebralis lumbar</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexion/extension (Fig. 3.1C)</td>
<td>Active</td>
<td>Active</td>
</tr>
<tr>
<td>Lateroflexion (Move torso left/right)</td>
<td>Active</td>
<td>Active</td>
</tr>
<tr>
<td>Homo-/hetero-lateral rotation (Rotation of torso)</td>
<td>Active</td>
<td>Active</td>
</tr>
<tr>
<td>Art. Intervertebralis Thoracic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexion/extension (Fig. 3.1C)</td>
<td>Active</td>
<td>Active</td>
</tr>
<tr>
<td>Scapulothoracal sliding surface, art. Acromioclavicular &amp; art. Sternoclavicular</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protracion/detraction (Move scapula front/back)</td>
<td>Active</td>
<td>Active</td>
</tr>
<tr>
<td>Elevation/depression (Move scapula up/down)</td>
<td>Active</td>
<td>Active</td>
</tr>
<tr>
<td>Art. Humeri</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ab-/adduction (Fig. 3.1D)</td>
<td>Active</td>
<td>Active</td>
</tr>
<tr>
<td>Ante-/retroflexion (Fig. 3.1E)</td>
<td>active</td>
<td>Active</td>
</tr>
<tr>
<td>Art. Cubiti &amp; art. Radiounaire</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexion/extension (Fig. 3.1C)</td>
<td>No motion</td>
<td>Active</td>
</tr>
<tr>
<td>Pro/supination (Fig. 3.1G)</td>
<td>No motion</td>
<td>Active</td>
</tr>
<tr>
<td>Art. Radiocarpale</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexion/extension (Fig. 3.1C)</td>
<td>No motion</td>
<td>Active</td>
</tr>
<tr>
<td>Radial/ulnair-abduction (Fig. 3.1I)</td>
<td>no motion</td>
<td>Active</td>
</tr>
<tr>
<td>Art. Metacarpophalangeae &amp; art. Interphalangeae</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flexion/extension (Fig. 3.1C)</td>
<td>No motion</td>
<td>Active</td>
</tr>
<tr>
<td>Radial/ulnair-abduction (Fig. 3.1I)</td>
<td>No motion</td>
<td>Active</td>
</tr>
</tbody>
</table>

Table 3.1 – Minimal joint motions needed to (sit-)snowboard
Summarizing table 3.1; 1) a snowboarder uses his/her legs to actively maneuver the snowboard, and 2) a sit-snowboarder uses his/her arms to actively maneuver the sit-snowboard. However a sit-snowboarder still needs to use his/her hips and knees passively to get in and out of the sit-snowboard. The hips are also used to tilt the torso to tilt the limiters. The abs and back muscles are important for snowboarding and sit-snowboarding. With these minimal joint motions in mind, the user group of a sit-snowboard can have a diverse set of physical impairments like, but certainly not limited to; cerebral palsy, spinal cord injury, Multiple Sclerosis (MS), Lou Gehrig’s Disease (ALS), Muscular Dystrophy (MD), and Ehlers-Danlos. The sit-snowboard can only be used in the early stages of MS, and ALS, for MD and Ehlers-Danlos the ability to sit-snowboard is depending on the severity of the injury and for cerebral palsy and spinal cord injuries the ability to sit-snowboard depends on the height of the injury. The height of the injury can maximally be at L2 (Fig. 3.2).
Figure 3.1 – Joints as discussed in Table 3.1 (1) Art. Humeri,  
2) Art. Cubiti & Art. Radiounaire,  
4) Scapulothoracaal sliding surface, art. Acromioclaviculare & art. Sternoclaviculare,  
5) Intervertabralis Thoracic,  
6) Intervertabralis lumbar,  
7) Art. Coxae,  
8) Art. Genus,  
9) Art. Talocalcaneonaviculare & art. Talocruralis

Figure 3.2 – Spinal cord levels and functions

References


Appendix 4
Notes Snowboard Funday
In this Appendix different potential user opinions are gathered from the Snowboard Funday, May 2013 Snowworld Zoetermeer.

<table>
<thead>
<tr>
<th>Person</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Man in wheelchair</td>
<td>I do not want to sacrifice the independence I have in my sit-ski for this device. Besides I do not trust this thing yet.</td>
</tr>
<tr>
<td>Women with trans-femoral amputation on one leg</td>
<td>Yeah I would not be one of the intended users, but I would not like the fact that someone would have to go with me all the time. (dependence)</td>
</tr>
<tr>
<td>Man in audience/crowd</td>
<td>How do you get up after a fall? <em>answer; someone has to pick you up</em> So you are basically helpless?</td>
</tr>
<tr>
<td>Young man in crowd</td>
<td>So when you fall you have to wait for someone to pick you up?....that’s awful.</td>
</tr>
<tr>
<td>Man with trans-tibial amputation of one leg</td>
<td>I am really happy that I can do everything myself</td>
</tr>
</tbody>
</table>

**From event reports**

<table>
<thead>
<tr>
<th>Person</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wilma</td>
<td>We had to wait one hour -&gt; that was not cool</td>
</tr>
<tr>
<td>Romanja</td>
<td>I enjoyed the entire trip and we even got a ski-degree</td>
</tr>
<tr>
<td>Darlyne</td>
<td>Today we did a blue slope</td>
</tr>
<tr>
<td>Makeda</td>
<td>I woke up myself, then I got dressed and got all my ski-clothes on myself. Skiing went very well, they even filmed me.</td>
</tr>
<tr>
<td>Ralph</td>
<td>David said my slalom was perfect, that was so cool</td>
</tr>
<tr>
<td>Sharon</td>
<td>After breakfast I put on my ski-boots with some help from Marloes</td>
</tr>
<tr>
<td>Rosan</td>
<td>They let me teach the warm-up</td>
</tr>
<tr>
<td>Jet</td>
<td>We did a race of who was the fastest, whoever had the fastest race and the least amount of time difference won.</td>
</tr>
<tr>
<td>Kevin</td>
<td>Slalom was the best, since it was kinda hard on the blue slope</td>
</tr>
<tr>
<td>Stan</td>
<td>I got up myself. The slalom was awesome and went superb.</td>
</tr>
</tbody>
</table>

These kids and grown-ups are very proud of their own achievements. This feeling of accomplishment is enhanced when they get to do things independently of others. This shows how the relationship between a feeling of accomplishment and doing things independently is very strong. People on the event also mentioned that doing things independently of others gives people a feeling of self-reliance and a positive self-esteem.

**Conclusions found in snow-funday magazines:**

- *Deelnemers meer zelfvertrouwen opbouwen; bereid hun gernzen te verleggen, zowel fysiek, sociaal als mentaal. Loosely translated;* Help participants to build on their self-esteem; willing to push the boundaries physically, socially, and mentally.
- *Ik ben geen gehandicapte maar een mens met een handicap. Loosely translated;* I am not a handicapped person, but a person with a handicap. I do not want to be dependent on other people. This is the mind-set I want to pass on to the younger generation of athletes. This is just as important as the actual skiing and snowboarding.

**Conclusions**

From this information it can be seen that the user wants to be independent, everything he/she can do him-/her-self feels like a personal achievement and gives personal satisfaction and self-confidence. Although help is part of everyday life this does not mean that products should be designed with a helping hand in mind, the more the user can do him-/her-self the better they will feel about the product.
Appendix 5

Interview Conclusions
In this appendix the conclusions from three different interviews can be found, on the disk at the back of this report the transcripts of these interviews can be found.

**User and adaptive snowboard instructor**  
*Conclusions of an interview with a 35 year old female adaptive snowboard instructor and founder of Prodaptive, she has also sit-snowboarded with every sit-snowboarding prototype from Prodaptive.*

There is a so called snowboard-feeling which differs from the ski-sensation. The interviewee feels one with her snowboard, on which she loves to play with her balance. Skiing seems more static to her. She also loves the world around snowboarding and the rebel attitude that comes with it, it is a little less traditional than skiing. To Gina the chairlift is an easy way to get up the slope, she likes to have some social interaction in the chairlift but that depends on her mood. Getting up the slope with a snowmobile is done more often in Canada, but using a snowmobile made her feel like cheating and disrupting the peacefulness of the mountains. All the prototypes were discussed and conclusions on that can be found in Appendix 1. A beginner snowboarder will go through the following exercises; 1) start of on the flat and take off and put on the gear, 2) explain how things work and introduced the beginner to some terms of use, 3) combine terminology with motions and feel what it is like to fall over, 4) then start with gliding, start of small and make it a little bigger every time, reducing the amount of help gradually, 5) start skidding down the slope, 6) start making turns, and eventually connecting turns.

**Paralympic sit-skier**  
*Conclusions of an interview with a male paralympic sit-skier, participated in the winter Paralympics in Sotsji.*

The interviewee is a professional sit-ski athlete who is part of the Paralympic team. Independence is very important to him and he wants to be able to do most things himself; getting up after a fall, getting in and out of chairlifts. He says that; As long as you have good upper body and arm strength, one should be able to do most things him-/her-self. Asking for a little help in awkward situations is not a problem, but keep this to a minimum. Getting in and out of the chairlift can be done with outriggers, good balance is important in this matter. It depends on the user whether or not he/she wants to slow down the chairlift with loading and unloading.

**Snowboarder**  
*Conclusions of an interview with a 24 year old female snowboarder.*

Snowboarding has a certain feel to it which is hard to describe in words, it is like a flow. One can steer the snowboard with minimal effort, which makes the user feel free and in the moment. Chairlifts bring some sort of nervousness for the interviewee, getting in and out is tricky and placing the snowboard correctly and maintaining a balanced body position with one foot unstrapped is hard. Being in a chairlift is a social thing, in which you can finally have a conversation which does not happen a lot on the slope. Surface lifts are tricky too since they make it hard for a snowboarder to balance out their weight, being sideways it the main problem to this.
Appendix 6

Snowboarders Questionnaire
What does snowboarding mean to you?

Hi, I am a Mechanical Engineering student from the Delft University of Technology and I am doing a study concerning people's experience of snowboarding. This study concerns my graduation project and is therefore very important to me. I would like to ask you some questions about this topic and it will take approximately 2 minutes. Thank you for donating a little of your time, to help me out with my research.

Start

What does snowboarding mean to you?

1. Do you snowboard?
   - Yes
   - No

2. How long have you been snowboarding?
   - I have been snowboarding for...

3. The last wintersport you went on what did you mainly do?
   - Snowboarding
   - Cross-country skiing
   - Monoskiing
   - Ice skating
   - Other [__]

4. How long have you been doing that?

5. What does snowboarding mean to you?

6.
What is the difference between snowboarding and skiing according to you?

7.

If you had to pick one thing that would make snowboarding snowboarding what would it be?

☐ Sitting sideways
☐ Having to lean forward and backward
☐ Having your feet attached on one board

8.

What does a chairlift add to your wintersport sensation?

☐ Time to relax/catch your breath
☐ Time to catch up with friends/family
☐ Time to ask for information from other snow-sporters
☐ Time to decide on what route to take next
☐ A way to get from A to B
☐ Other:

9.

How important is the social aspect of the chairlift to you? (Interaction with people)

not important

important

Done! Send it!

Thank you so much for your participation, I appreciate your effort a lot!
Appendix 7

User Questionnaire (English)
How do you feel about this?

Hi, I am a MSc in Mechanical Engineering student from the Delft University of Technology and I am doing a study concerning people’s experience of adaptive equipment and snowboarding. This study influences the design of a sit-snowboard, which means you are part of the creation of an awesome snowboard you might actually be able to use later on. I would like to ask you some questions about the topic and it will take approximately 10 minutes. Thank you for donating a little of your time to help me out with my research.

Start

How do you feel about this?

This survey can be done anonymously, but in order to design a product that is most suited for the intended user, I would like to take your email address if you don’t mind. This would allow me to contact you if I need to ask you for your opinion or to ask you if you would like to test the product. In case you leave your email, you could be part of the design of an awesome sit-snowboard!

1. What is your name?

2. What is your email address?

3. Do you have a disability/handicap?
   - Yes
   - No

4. Do/did you snowboard?
   - Yes
   - No

5. How long have you been snowboarding?
6. The last wintersport you went on what did you mainly do?
   - Skiing
   - Snowboarding
   - Ski-skiing
   - Snow-skiing
   - Other: [ ]

7. How long have you been doing that?
   [ ]

8. What does snowboarding mean to you?
   [ ]

9. What is the difference between snowboarding and skiing according to you?
   [ ]

10. If you had to pick one thing that would make snowboarding snowboarding what would it be?
    - Sitting sideways
    - Having to lean forward and backward
    - Being attached to one board
    - Other: [ ]

11. What does a chairlift add to your wintersport sensation?
    - Time to relax/catch your breath
    - Time to catch up with friends/family
    - Time to ask for information from other snow-sportsers
    - Time to decide on what route to take next
    - Ways to get from A to B
    - Other: [ ]

12. How important is the social aspect of the chairlift to you? (Interaction with people)
    - Not important
    - Important
13. To what extent would you consider asking for help as opposed to the amount of minutes you will have to work for it yourself? In the following cases which statement would you prefer?

<table>
<thead>
<tr>
<th>Work Duration</th>
<th>Preference</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 seconds independent work</td>
<td>○ ○ Ask for a little push from someone</td>
</tr>
<tr>
<td>1 minute independent work</td>
<td>○ ○ Ask for help lifting your equipment</td>
</tr>
<tr>
<td>5 minute independent work</td>
<td>○ ○ Ask for help lifting your equipment</td>
</tr>
<tr>
<td>10 minute independent work</td>
<td>○ ○ Ask for help lifting your equipment</td>
</tr>
<tr>
<td>30 minute independent work</td>
<td>○ ○ Ask for help lifting your equipment</td>
</tr>
</tbody>
</table>

14. To what extent would you consider asking for help as opposed to the amount of minutes you will have to work for it yourself? In the following cases which statement would you prefer?

<table>
<thead>
<tr>
<th>Work Duration</th>
<th>Preference</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 seconds independent work</td>
<td>○ ○ Ask for help lifting your equipment</td>
</tr>
<tr>
<td>1 minute independent work</td>
<td>○ ○ Ask for help lifting your equipment</td>
</tr>
<tr>
<td>5 minute independent work</td>
<td>○ ○ Ask for help lifting your equipment</td>
</tr>
<tr>
<td>10 minute independent work</td>
<td>○ ○ Ask for help lifting your equipment</td>
</tr>
<tr>
<td>30 minute independent work</td>
<td>○ ○ Ask for help lifting your equipment</td>
</tr>
</tbody>
</table>

15. To what extent would you consider asking for help as opposed to the amount of minutes you will have to work for it yourself? In the following cases which statement would you prefer?

<table>
<thead>
<tr>
<th>Work Duration</th>
<th>Preference</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 seconds independent work</td>
<td>○ ○ Ask for help lifting yourself</td>
</tr>
<tr>
<td>1 minute independent work</td>
<td>○ ○ Ask for help lifting yourself</td>
</tr>
<tr>
<td>5 minute independent work</td>
<td>○ ○ Ask for help lifting yourself</td>
</tr>
<tr>
<td>10 minute independent work</td>
<td>○ ○ Ask for help lifting yourself</td>
</tr>
<tr>
<td>30 minute independent work</td>
<td>○ ○ Ask for help lifting yourself</td>
</tr>
</tbody>
</table>

16. To what extent would you consider compromising your independence as opposed to the amount of money you spend? In the following cases which statement would you prefer?

<table>
<thead>
<tr>
<th>Equipment Cost</th>
<th>Preference</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 euro</td>
<td>○ ○ Need a push from someone else to get into the chairlift</td>
</tr>
<tr>
<td>100 euro</td>
<td>○ ○ Need a push from someone else to get into the chairlift</td>
</tr>
<tr>
<td>250 euro</td>
<td>○ ○ Need a push from someone else to get into the chairlift</td>
</tr>
</tbody>
</table>
### Design and Preliminary Testing of a Novel Sit-Snowboard, Enabling Chairlift Usage

<table>
<thead>
<tr>
<th>Equipment Cost</th>
<th>Preference</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>500 euro</td>
<td>O O O O O</td>
<td>Need a push from someone else to get into the chairlift</td>
</tr>
<tr>
<td>1000 euro</td>
<td>O O O O O</td>
<td>Need a push from someone else to get into the chairlift</td>
</tr>
<tr>
<td>3000 euro</td>
<td>O O O O O</td>
<td>Need a push from someone else to get into the chairlift</td>
</tr>
</tbody>
</table>

### Question 17.

To what extent would you consider compromising our independence as opposed to the amount of money you spend? In the following cases which statement would you prefer?

<table>
<thead>
<tr>
<th>Equipment Cost</th>
<th>Preference</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 euro</td>
<td>O O O O O</td>
<td>Chairlift has to be stopped to get into and out of it</td>
</tr>
<tr>
<td>100 euro</td>
<td>O O O O O</td>
<td>Chairlift has to be stopped to get into and out of it</td>
</tr>
<tr>
<td>250 euro</td>
<td>O O O O O</td>
<td>Chairlift has to be stopped to get into and out of it</td>
</tr>
<tr>
<td>500 euro</td>
<td>O O O O O</td>
<td>Chairlift has to be stopped to get into and out of it</td>
</tr>
<tr>
<td>1000 euro</td>
<td>O O O O O</td>
<td>Chairlift has to be stopped to get into and out of it</td>
</tr>
<tr>
<td>3000 euro</td>
<td>O O O O O</td>
<td>Chairlift has to be stopped to get into and out of it</td>
</tr>
</tbody>
</table>

### Question 18.

To what extent would you consider compromising our independence as opposed to the amount of money you spend? In the following cases which statement would you prefer?

<table>
<thead>
<tr>
<th>Equipment Cost</th>
<th>Preference</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 euro</td>
<td>O O O O O</td>
<td>Need someone else to pick me up after a fall</td>
</tr>
<tr>
<td>100 euro</td>
<td>O O O O O</td>
<td>Need someone else to pick me up after a fall</td>
</tr>
<tr>
<td>250 euro</td>
<td>O O O O O</td>
<td>Need someone else to pick me up after a fall</td>
</tr>
<tr>
<td>500 euro</td>
<td>O O O O O</td>
<td>Need someone else to pick me up after a fall</td>
</tr>
<tr>
<td>1000 euro</td>
<td>O O O O O</td>
<td>Need someone else to pick me up after a fall</td>
</tr>
<tr>
<td>3000 euro</td>
<td>O O O O O</td>
<td>Need someone else to pick me up after a fall</td>
</tr>
</tbody>
</table>

### Question 19.

To what extent would you consider compromising our independence as opposed to the amount of money you spend? In the following cases which statement would you prefer?

<table>
<thead>
<tr>
<th>Equipment Cost</th>
<th>Preference</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 euro</td>
<td>O O O O O</td>
<td>Cannot get into the chairlift, only surface (sleep lift), carpet and rope lifts</td>
</tr>
<tr>
<td>100 euro</td>
<td>O O O O O</td>
<td>Cannot get into the chairlift, only surface (sleep lift), carpet and rope lifts</td>
</tr>
<tr>
<td>250 euro</td>
<td>O O O O O</td>
<td>Cannot get into the chairlift, only surface (sleep lift), carpet and rope lifts</td>
</tr>
<tr>
<td>500 euro</td>
<td>O O O O O</td>
<td>Cannot get into the chairlift, only surface (sleep lift), carpet and rope lifts</td>
</tr>
<tr>
<td>1000 euro</td>
<td>O O O O O</td>
<td>Cannot get into the chairlift, only surface (sleep lift), carpet and rope lifts</td>
</tr>
<tr>
<td>3000 euro</td>
<td>O O O O O</td>
<td>Cannot get into the chairlift, only surface (sleep lift), carpet and rope lifts</td>
</tr>
</tbody>
</table>

---

www.thesisinics.com
Please show how important you think the following things are in the design of a sit-snowboard you would want to buy:

<table>
<thead>
<tr>
<th>Feature</th>
<th>Not Important</th>
<th>Somewhat Important</th>
<th>Very Important</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ease of use</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Independence</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Safety</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stability</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Robust</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tough looking</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simple design</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Price</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Done! Send!

www.thetools.com

Thank you so much for your participation, I appreciate your effort a lot!

www.thetools.com
Appendix 8
User Questionnaire (Dutch)
Hoe denkt u erover?

Hey, ik ben Michelle, een werktuigbouwkundige student van de Technische Universiteit van Delft. Voor mijn afstuderen doe ik onderzoek naar aangepaste hulpmiddelen en ervaringen van mensen met snowboards. Dit onderzoek is erg belangrijk voor mijn verdere ontwerp van een aangepast snowboard en ik zou u hierover graag wat vragen willen stellen. Deelnemen aan deze enquête houdt dus ook in dat u directe invloed hebt op het ontwerp van een zit-snowboard dat u mensen later zelf kunt gebruiken. Het neemt ongeveer 10 minuten van uw tijd in beslag en ik ben er erg mee geholpen.

Start

Hoe denkt u erover?

Dit onderzoek kan anoniem gedaan worden, maar voor mij is het heel erg fijn als ik een naam bij de resultaten zie. Als u mij nog verder wilt helpen kunt u ook uw email adres achterlaten. Hiermee kan ik u dan bereiken als ik uw gebruikelijke mening over een bepaalde vraagstuk wil hebben. Als ik een testpersoon nodig heb, kunt u hiermee dus een groot deel gaan uiteen maken van het ontwerp van het zitt- snowboard.

1. Wat is uw naam?

2. Wat is uw email adres?

3. Heeft u een beperking/handicap?
   - Ja
   - Nee

4. Deet/deed u aan snowboarden?
   - Ja
   - Nee

5.
6. Hoe lang doet u al aan snowboarden/heeft u al aan snowboarden gedaan?

7. Wat deed u het meest op uw laatste wintersport?
   - skiën
   - snowboarden
   - skiën met snowboard
   - mono-skiën
   - bij foto's
   - anders:

8. Hoe lang doet u dit al?

9. Wat betekend snowboarden voor u?

10. Wat vindt u het verschil tussen skiën en snowboarden?

11. Als u een ding moet kiezen dat snowboarden snowboarden maakt, wat zou dat dan zijn?
   - het schaatsen
   - het naar voren en achteren lopen
   - dat je vast zit aan 1 board
   - anders:

12. Wat voegt de stoeltjeslift toe aan uw wintersport ervaring?
   - de tijd om op adem te komen
   - de tijd om met vrienden te socialiseren
   - de tijd om andere wintersporters om informatie te vragen
   - de tijd om een nieuwe route te bepalen
   - Jean maar om van A naar B te komen
   - anders:

13. Hoe belangrijk is het sociale aspect van de stoeltjeslift voor u?
   - niet belangrijk
   - belangrijk
## Design and Preliminary Testing of a Novel Sit-Snowboard, Enabling Chairlift Usage

13. **Om erachter te komen hoeveel moeilijk u zelf wil doen en om welke mate van hulp u wilt vragen; kunt u invullen welke van de volgende stellingen uw voorkeur heeft?**

<table>
<thead>
<tr>
<th>Time</th>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 seconden zelf moeite doen</td>
<td>☐ ☐</td>
<td>Iemand anders vragen om een duwtje</td>
</tr>
<tr>
<td>1 minuut zelf moeite doen</td>
<td>☐</td>
<td>Iemand anders vragen om een duwtje</td>
</tr>
<tr>
<td>5 minuut zelf moeite doen</td>
<td>☐</td>
<td>Iemand anders vragen om een duwtje</td>
</tr>
<tr>
<td>10 minuut zelf moeite doen</td>
<td>☐</td>
<td>Iemand anders vragen om een duwtje</td>
</tr>
<tr>
<td>30 minuut zelf moeite doen</td>
<td>☐</td>
<td>Iemand anders vragen om een duwtje</td>
</tr>
</tbody>
</table>

14. **Om erachter te komen hoeveel moeilijk u zelf wilt doen en om welke mate van hulp u wilt vragen; kunt u invullen welke van de volgende stellingen uw voorkeur heeft?**

<table>
<thead>
<tr>
<th>Time</th>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 seconden zelf moeite doen</td>
<td>☐</td>
<td>Hulp vragen om uw spullen te tillen</td>
</tr>
<tr>
<td>1 minuut zelf moeite doen</td>
<td>☐</td>
<td>Hulp vragen om uw spullen te tillen</td>
</tr>
<tr>
<td>5 minuut zelf moeite doen</td>
<td>☐</td>
<td>Hulp vragen om uw spullen te tillen</td>
</tr>
<tr>
<td>10 minuut zelf moeite doen</td>
<td>☐</td>
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<tr>
<td>30 minuut zelf moeite doen</td>
<td>☐</td>
<td>Hulp vragen om uw spullen te tillen</td>
</tr>
</tbody>
</table>

15. **Om erachter te komen hoeveel moeilijk u zelf wilt doen en om welke mate van hulp u wilt vragen; kunt u invullen welke van de volgende stellingen uw voorkeur heeft?**

<table>
<thead>
<tr>
<th>Time</th>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 seconden zelf moeite doen</td>
<td>☐</td>
<td>Hulp vragen om u zelf op te tillen</td>
</tr>
<tr>
<td>1 minuut zelf moeite doen</td>
<td>☐</td>
<td>Hulp vragen om u zelf op te tillen</td>
</tr>
<tr>
<td>5 minuut zelf moeite doen</td>
<td>☐</td>
<td>Hulp vragen om u zelf op te tillen</td>
</tr>
<tr>
<td>10 minuut zelf moeite doen</td>
<td>☐</td>
<td>Hulp vragen om u zelf op te tillen</td>
</tr>
<tr>
<td>30 minuut zelf moeite doen</td>
<td>☐</td>
<td>Hulp vragen om u zelf op te tillen</td>
</tr>
</tbody>
</table>

16. **Om erachter te komen hoeveel geld u bereid bent uit te geven voor verschillende mate van zelfstandigheid; kunt u invullen welke van de volgende stellingen uw voorkeur heeft?**

<table>
<thead>
<tr>
<th>Option</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 euro apparatuur</td>
<td>Een duwtje van iemand anders nodig om de lift te openen</td>
</tr>
</tbody>
</table>
### DESIGN AND PRELIMINARY TESTING OF A NOVEL SIT-SNOWBOARD, ENABLING CHAIRLIFT USAGE

<table>
<thead>
<tr>
<th>Apparatuur (€)</th>
<th>Option 1</th>
<th>Option 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>een duwstaak van iemand anders nodig om de lift in te komen</td>
<td>een duwstaak van iemand anders nodig om de lift in te komen</td>
</tr>
<tr>
<td>250</td>
<td>een duwstaak van iemand anders nodig om de lift in te komen</td>
<td>een duwstaak van iemand anders nodig om de lift in te komen</td>
</tr>
<tr>
<td>500</td>
<td>een duwstaak van iemand anders nodig om de lift in te komen</td>
<td>een duwstaak van iemand anders nodig om de lift in te komen</td>
</tr>
<tr>
<td>1000</td>
<td>een duwstaak van iemand anders nodig om de lift in te komen</td>
<td>een duwstaak van iemand anders nodig om de lift in te komen</td>
</tr>
<tr>
<td>3000</td>
<td>een duwstaak van iemand anders nodig om de lift in te komen</td>
<td>een duwstaak van iemand anders nodig om de lift in te komen</td>
</tr>
</tbody>
</table>

17. **Om erachter te komen hoeveel geld u bereid bent uit te geven voor verschillende mate van zelfstandigheid kunt u invullen welke van de volgende stellingen uw voorkeur heeft?**

<table>
<thead>
<tr>
<th>Apparatuur (€)</th>
<th>Option 1</th>
<th>Option 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>de stoeltjeslift moet worden stilgezet om in en uit te kunnen stappen</td>
<td>de stoeltjeslift moet worden stilgezet om in en uit te kunnen stappen</td>
</tr>
<tr>
<td>100</td>
<td>de stoeltjeslift moet worden stilgezet om in en uit te kunnen stappen</td>
<td>de stoeltjeslift moet worden stilgezet om in en uit te kunnen stappen</td>
</tr>
<tr>
<td>250</td>
<td>de stoeltjeslift moet worden stilgezet om in en uit te kunnen stappen</td>
<td>de stoeltjeslift moet worden stilgezet om in en uit te kunnen stappen</td>
</tr>
<tr>
<td>500</td>
<td>de stoeltjeslift moet worden stilgezet om in en uit te kunnen stappen</td>
<td>de stoeltjeslift moet worden stilgezet om in en uit te kunnen stappen</td>
</tr>
<tr>
<td>1000</td>
<td>de stoeltjeslift moet worden stilgezet om in en uit te kunnen stappen</td>
<td>de stoeltjeslift moet worden stilgezet om in en uit te kunnen stappen</td>
</tr>
<tr>
<td>3000</td>
<td>de stoeltjeslift moet worden stilgezet om in en uit te kunnen stappen</td>
<td>de stoeltjeslift moet worden stilgezet om in en uit te kunnen stappen</td>
</tr>
</tbody>
</table>

18. **Om erachter te komen hoeveel geld u bereid bent uit te geven voor verschillende mate van zelfstandigheid kunt u invullen welke van de volgende stellingen uw voorkeur heeft?**

<table>
<thead>
<tr>
<th>Apparatuur (€)</th>
<th>Option 1</th>
<th>Option 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>iemand anders moet me overeind helpen na een val</td>
<td>iemand anders moet me overeind helpen na een val</td>
</tr>
<tr>
<td>100</td>
<td>iemand anders moet me overeind helpen na een val</td>
<td>iemand anders moet me overeind helpen na een val</td>
</tr>
<tr>
<td>250</td>
<td>iemand anders moet me overeind helpen na een val</td>
<td>iemand anders moet me overeind helpen na een val</td>
</tr>
<tr>
<td>500</td>
<td>iemand anders moet me overeind helpen na een val</td>
<td>iemand anders moet me overeind helpen na een val</td>
</tr>
<tr>
<td>1000</td>
<td>iemand anders moet me overeind helpen na een val</td>
<td>iemand anders moet me overeind helpen na een val</td>
</tr>
<tr>
<td>3000</td>
<td>iemand anders moet me overeind helpen na een val</td>
<td>iemand anders moet me overeind helpen na een val</td>
</tr>
</tbody>
</table>

19. **Om erachter te komen hoeveel geld u bereid bent uit te geven voor verschillende mate van zelfstandigheid kunt u invullen welke van de volgende stellingen uw voorkeur heeft?**

<table>
<thead>
<tr>
<th>Apparatuur (€)</th>
<th>Option 1</th>
<th>Option 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>u kan niet in de stoeltjeslift alleen slepen zijn toegestaan</td>
<td>u kan niet in de stoeltjeslift alleen slepen zijn toegestaan</td>
</tr>
<tr>
<td>100</td>
<td>u kan niet in de stoeltjeslift alleen slepen zijn toegestaan</td>
<td>u kan niet in de stoeltjeslift alleen slepen zijn toegestaan</td>
</tr>
<tr>
<td>250</td>
<td>u kan niet in de stoeltjeslift alleen slepen zijn toegestaan</td>
<td>u kan niet in de stoeltjeslift alleen slepen zijn toegestaan</td>
</tr>
<tr>
<td>500</td>
<td>u kan niet in de stoeltjeslift alleen slepen zijn toegestaan</td>
<td>u kan niet in de stoeltjeslift alleen slepen zijn toegestaan</td>
</tr>
</tbody>
</table>
20.

Kunt u alstublieft aangeven hoe belangrijk u de volgende eigenschappen vindt in een zit-snowboard dat u eventueel wil gebruiken?

<table>
<thead>
<tr>
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<th>heel erg belangrijk</th>
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</thead>
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<td>○</td>
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<td>○</td>
</tr>
<tr>
<td>Veiligheid</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Gewicht</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Hoogte</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Stabilität</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>Robuustheid</td>
<td>○</td>
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<tr>
<td>Sterkerhartig</td>
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<td>○</td>
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<tr>
<td>Simpele constructie</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

Prijs

○ ○ ○ ○ ○

Klaar! Verzenden!

Heel erg bedankt voor de moeite!
Appendix 9
Questionnaire Results
In this Appendix information can be found on the questionnaire results from the questionnaire held with snowboarders (App. 6) and the questionnaire held with potential users (App. 7, 8).

**Snowboarders**

Out of 52 respondents only 27 results could be used, since some did not complete the questionnaire and others were skiers.

The 27 snowboarding respondents shared an average of 6.7 years (st. dev. 3.6 years) of experience in snowboarding.

4 out of the 27 respondents mentioned that they skied the last year, these respondents have an average of 12.7 years (st. dev. 7.93 years) of experience in skiing and mentioned to have tried snowboarding for a couple of years but having gone back to skiing after all.

On the questions “what does snowboarding mean to you?” people mentioned the thrill, the mountains/outdoors, sports-factor, relaxation, spending time with family. 10 out of 27 mentioned freedom and 12 out of 27 mentioned either fun or pleasure.

Most snowboarders felt that the fact that your feet are attached to one board makes snowboarding into the sport that it is, followed by having to lean forward and backwards, with sitting sideways to be the last option but still chosen by 5 respondents (Fig. 9.1).

![Graph of the answers to the question; What defines snowboarding?](image)

The answers given to the question “what does a chairlift add to your wintersport sensation?” can be seen in Figure 9.2.
It can be concluded that the time in a chairlift is experienced as social interaction time. The answers given with the option other was; enjoying the scenery.
Interesting thing to see was that on the question of how important the social aspect in the chairlift actually is the responses were much divided (Fig. 9.3). 1 means not important, scaling up to 5 which means important.

**Potential users**

The answers given in this section are the answers to the questionnaires found in Appendix 7 and 8. Out of 47 respondents 17 respondents could be used, since other were either not handicapped or did not fill out the entire questionnaire. All these 17 respondents had a handicap that landed them in a wheelchair like cerebral palsy, paraplegia, and ehlers danlos syndroom.

4 out of 17 respondents had snowboarded before one of them has spina bifida and the others have a spinal cord injury. The people with spinal cord injury added that they did not snowboard since their accident. Two snowboarders had two years of experience, one had one year of experience and one person had 10 years of experience. 7 people have done sit-skiing, they share an average 7.5 years (st. dev. 10.07 years) of experience.

Even though some respondents mention that they do not see themselves snowboarding any time soon, the question of what snowboarding means to them was answered in the following way; 3 mentioned fun, 3 mentioned a sense of freedom and one person even said that the snowboard feeling cannot be matched or compared to a skiing sensation.

To the question “what defines snowboarding?” the respondents answered that sitting sideways is the main component that defines snowboarding, closely followed by the feet being attached to one board (Fig. 9.4). Leaning back and forth finished last with the option other. In the option other people mentioned to have no clue, the “feeling”, and the fact that you go without any outriggers/poles.

![Graph of the answers to the question; What defines snowboarding?](image)

Compared to the regular snowboarders, the potential sit-snowboarders have different opinions towards the sensation that a chairlift adds to the snowboard experience. As said before the snowboarders look at the chairlift ride as social time, whilst Figure 9.5 shows that potential sit-snowboarders view the chairlift mostly as a time to relax and a way to get from A to B. With the option other the sit-snowboarders also mentioned time to view the mountain and enjoy the scenery.
When specifically asked about the social aspect of the chairlift, see Figure 9.6, the respondents do answer that they think the social aspect is important.

The final questions of the questionnaire are formulated to figure out the importance of certain design aspects like; the amount of time willing to take to perform tasks, the amount of money willing to pay for certain design features.
Figures 9.7 to 9.13 show the answers to these questions, at some point in every graph it can be seen that the user would rather ask for help than spend more time, and would rather not have a feature than spend more money.

From Figure 9.7 the conclusion can be taken that most users will ask for a little push if they need to spend more than 5-10 minutes doing that task themselves.

From Figure 9.8 the conclusion can be taken that most users will ask for help lifting equipment if they need to spend more than 5-10 minutes doing that task themselves.
Figure 9.9 – A graph that shows when people would rather ask for help to lift themselves and when they would rather spend time on performing a task.

From Figure 9.9 the conclusion can be taken that most users will ask for help lifting themselves if they need to spend more than 10-30 minutes doing that task themselves.

Figure 9.10 – A graph that shows when people would rather ask for a push to get into the chairlift and when they would rather spend money to be able to do that task themselves.

From Figure 9.10 the conclusion can be taken that most users will ask for a push if they need to spend more than 250-500 euro for design features so they can do that task themselves.
From Figure 9.11 the conclusion can be taken that most users will rather have the lift stopped to get in and out than to spend more than 100-250 euro for design features so they can do that task themselves.

From Figure 9.12 the conclusion can be taken that most users will rather need help to get up after a fall than to spend more than 250-500 euro for design features so they can do that task themselves.
From Figure 9.13 the conclusion can be taken that most users will rather not be able to ride the chairlift than to spend more than 500-1000 euro for a design feature so they can ride the chairlift.

Figure 9.14 shows all the design aspects that were laid out to the respondents, all the respondents could rate it with a scale from 1-5 with 1 meaning that it is not important and 5 meaning it is very important. In Figure 9.14 the top rated number out of that scale is set out. From this Figure it can be concluded that price is least important, and safety, control, and ease of use is most important in the design for this user group. Closely followed by independence, weight, and stability.
In Figure 9.15, these same answers are displayed with their averages on the scales. Here it can clearly be seen that the user are a little more divided in certain matters. From this Figure it can be concluded that control is the most important design aspect, closely followed by ease of use and safety, but also independence and stability. What this data shows is that price is important to some people but certainly not all, and that the looks are less important.

**Conclusions**

Asking for help is not a problem as long as often recurring maneuvers or actions can be performed with the least amount of help leaving them in control. The handicapped user is prepared to pay 250-500 euro if this means independence, he/she does not care as much about stopping the chairlift. The potential-user is willing to pay 500-1000 euro’s for being able to ride the chairlift as opposed to not being able to ride the chairlift.

Appearances are not that important, which makes the sit-snowboard a typical form follows functions design. A more remarkable thing is that price is not that important to this user. This sector gets a lot of money compensations and most of the people approached for this research are part of a sports team which normally gets a lot of sponsoring. Another reason could be that equipment for handicapped people and especially sports equipment is very expensive already.
Appendix 10

Snowboards
In this Appendix information can be found on the design of snowboards and terms used with snowboards. This is relevant since the sit-snowboard design will be mounted on a snowboard.

A snowboard is build out of different layers, these layers determines not only the shape but also the “attitude” of the snowboard. In order to understand the definitions mentioned look at Figure 10.1, 10.2, and 1 (paper).

The binding mounts are also called inserts and the Nose of the snowboard is also called Tip of the snowboard. The effective edge is the edge that can engage in the turn and has a side cut radius, which is influenced by the waist of the snowboard. This side cut radius influences the turning radius of the snowboard. A snowboard can flex about the length radius of the snowboard further referred to as the torsion of the snowboard (Fig. 10.3), and the snowboard can flex about the waist of the snowboard(Fig. 10.3) (further referred to as the flexion of the snowboard).

With different snowboards come different types of attachment (Fig. 10.4). Most snowboards use standard two by four inserts to attach the bindings to the snowboard;
this means that the inserts are spaced 2 by 4 cm from one another. Another very common mounting option is the four by four inserts, which are spaced 4 cm from one another. These inserts attach the bindings to the snowboard with four M6 bolts per binding. Apart from this standard insert configurations Burton (a well-known snowboard brand) has two very own ways of attachment to the snowboard.

A snowboard can have a twin-tip, be a directional-twin, or have a directional shape (Fig. 10.5). The twin-tip allows the user to snowboard with the snowboard both ways since the tip and the tail are the same shape. The directional-twin is preferably ridden in one direction but can still be snowboarded on in the opposite direction, the so called fakie. The directional shape only allows the user to snowboard one way, since the shape of the snowboard will catch an edge when snowboarding the other way.

Apart from the type of inserts and styles of snowboards, snowboards differ in other ways; length, width, weight, bending, and flexing of the snowboard. The length, width, and weight are mostly dependent on the user, since they are determined by the weight
and the length of the user. The bending and flexing is more dependent on the brand and type of snowboard, which is chosen on the users preferences and snowboarding style. The shorter a snowboard the easier to steer but at higher speeds a shorter snowboard will start to get unstable and start to move unintentionally, so called chatter. The amount of chatter also depends on the flexibility of the snowboard.

There are three main type of snowboards from flexible to stiff there are; Freestyle, All mountain, and Alpine snowboards. Last but not least is the profile of the snowboard (Fig. 10.6): A traditional camber, a rocker, a flat camber, and a combo.

![Figure 10.6 - Four different snowboard camber configurations: Traditional, Reverse, Flat, and Combination](image)

During this research a twin tip, all mountain snowboard was used with a traditional camber. There were two Atomic Piq, learn to ride, rental snowboards from Snowworld with a length of 1.55 m available. These snowboards have 8 four by four inserts per side with a spacing of 40 cm in between them. These two snowboards have been used in the tests.

**References**


ATB shop [Web page], [cited 2013, 12-2013], available from [http://www.atbshop.co.uk/snowboard-shop](http://www.atbshop.co.uk/snowboard-shop)

Clever shoppers [Web page], [cited 2013, 12-2013], available from [http://clever-shoppers.co.uk/?tag=snowboards](http://clever-shoppers.co.uk/?tag=snowboards)

Appendix 11

Sit-Snowboarding
In this appendix information can be found on the movements, accompanied by the terms used for these movements, used during sit-snowboarding.

**Definitions**

**Toe side turn:** A turn on the toe side edge of the snowboard.

**Heel side turn:** A turn on the heel side edge of the snowboard.

**Skidding:** When the user is skidding the snowboard moves down the slope in a sideways manner whilst keeping the leading edge on one edge either the heel side edge or toe side edge. The skidding speed can be controlled by controlling the angle between the snowboard and the snow. A bigger angle equals less speed whilst a smaller angle provides more speed.

**Skidded turns:** Turns where the tail of the snowboard does not follow the same path as the tip of the snowboard. Leaves snow spray, making smeared marks. For less experienced snowboarders. Creates braking forces, slows down.

**Carved turns:** Tail and tip take the same path through the snow. Leaves sharp marks in the snow (pencil lines), no snow spray. Does not provide as much braking forces, allows for a fast turn [11.1] [11.2] [11.3].

**Regular turns:** Center of mass following the same path as the snowboard. Looks rigid and looks like the body and the snowboard are one uniform hunk of material that all moves in the same place at the same time.

**Dynamic turns:** Center of mass follows a significantly different path than the snowboard. Activity in the joints of the body, the legs, the ankles, whilst the hips are flexible [11.1].

**Movements**

When a beginner starts snowboarding there are certain steps that will be followed, these steps can roughly be divided into three steps. First the front foot of the beginner will be strapped onto the snowboard and the beginner will start skating around to get comfortable with sliding in the snow. When the user feels comfortable the next step is skidding down the slope. With skidding the user will press one of the snowboard edges into the snow, the skidding is used as an exercise to create speed control and edge awareness [11.4] which is very important for the next and last step. When the edge is put into the snow more the snowboard will stop, when the pressure is taken of the edge the angle the snowboard makes with the snow will become smaller. With this smaller angle the snowboard will start sliding. The last step is making turns. There are three parts to turning; 1) the launch phase, in which the snowboarder let’s his/her body turn in the direction he/she wants which will make the snowboard twist, 2) the turn phase, in which the snowboarder will pressure the edge of his/her snowboard to complete the turn and control the speed of his/her snowboard, and 3) the release phase, in which the snowboarder let’s his/her snowboard go straight and flat down the hill. Pressuring the edge during the turn phase is done by putting...
more weight onto the edge, which in turn is done by placing the COM onto the edges [11.5][11.6]. For a snowboarder to initiate a turn the head, the arms, and upper body are engaged and used as a balance mechanism [11.7], by applying a torsion moment on the snowboard the turn is initiated. To maintain balance on a snowboard the user should have bent legs, bent ankles, bent knees, bent hips, and the body should be stacked upright over that bend base [11.8][11.9]. The legs and feet are active during the entire turn and will guide the torsion motions initiate by the upper body to the snowboard [11.7]. The snowboarder needs to have his/her weight centered over the edge that is engaging in the surface. Centripetal force, gravitational force should be balanced at all times to avoid falling (Fig. 3B paper). The tips of a snowboard are wider than the middle, the snowboard is shaped in such a way that the snowboard curves along the edges [11.10]. The amount of flexion (Fig. 11.2) determines the radius of the turn, the amount of flexion is determined by the amount of pressure put on the edge and the tilting of the knees.

The three steps in learning how to snowboard are also found in sit-snowboarding. The skating in done by pushing the sit-snowboarder and letting him/her feel the motion and making slight turns using the handlebars. The second step, skidding, is done on the slope in a similar setting as snowboarding. The sit-snowboarder will put his/her weight on one of the edges by using the so called limiters. By using the limiters the sit-snowboarder can place his/her COM on one of the edges and drive this edge into the snow (Fig. 11.3). When the sit-snowboarder leans further to one side the COM will pass the edge of the snowboard making it tilt, this drives the edge further into the snow. The tilt of the limiters in combination with the use of the handlebars determines the tilt of the snowboard, which in turn determines the speed during skidding.
Learning to control this skidding motion does the same as it does in the learning cycle of a snowboarder, it allows for training of speed control and edge awareness which can be used later in turning. For the last step, turning, there are the same three parts as with snowboarding; 1) the launch phase, in which the sit-snowboarder will apply forces to the handlebars to make the snowboard twist, 2) the turn phase, in which the edge is pressured by using the abdominal, back muscles, and the limiters to complete the turn and control the speed of the sit-snowboard, and 3) the release phase, in which the sit-snowboarder let’s his/her sit-snowboard go straight and flat down the hill. The two handlebars on MINI allow for the sit-snowboarder to apply a torsion force onto the snowboard to initiate and produce a turn (Fig. 11.4). The handlebars supersede the functioning of the feet, since the feet normally initiate a turn by twisting the snowboard. The amount of flexion in the snowboard is determined by the amount of pressure that the user puts on the handlebars.[11.10-11.16]

**Force analysis of limiter**

Assuming that the rubber in the limiter acts as a linear spring, a model can be made of the behavior of the limiter (Fig.11.5, 11.6, 11.7). Based on the tilt angle of the limiter the rubber will be pressed a certain amount which will generate a force (Fig. 11.6).
Based on these assumptions eq. 11.1-11.4 form the model [11.16].

\[
F_x = \int L w(x) dx = \int_A dA = A \quad \text{[eq. 11.1]}
\]

\[
\bar{x} = \frac{\int L w(x) dx}{\int L w(x) dx} = \frac{\int_A x dA}{\int_A dA} \quad \text{[eq. 11.2]}
\]

\[
w(x) = c \cdot u(x) \quad \text{[eq. 11.3]}
\]

\[
u = x \left( \frac{(hr)_{in}}{2bp} \right) \quad \text{[eq. 11.4]}
\]

Combining eq. 11.1 with eq. 11.3 and eq. 11.4:

\[
F_x = \int L c \cdot x \left( \frac{(hr)_{in}}{2bp} \right) dx = c \cdot \frac{1}{4} \cdot bp \cdot (hr)_{in} \quad \text{[eq. 11.5]}
\]

Combining eq. 11.5 with eq. 11.2:

\[
\bar{x} = \frac{\int L c \cdot x \left( \frac{(hr)_{in}}{2bp} \right) dx}{\int L c \cdot x \left( \frac{(hr)_{in}}{2bp} \right) dx} = \frac{1}{3} \cdot bp \quad \text{[eq. 11.6]}
\]

When it is assumed that the rubber has quadratic behavior, so \( u = x^2 \left( \frac{(hr)_{in}}{2bp} \right) \) (Fig. 11.4), this would mean: \( D_x = c \cdot \frac{1}{12} \cdot bp^2 \cdot (hr)_{in} \) and \( \bar{x} = \frac{3}{8} \cdot bp \)

Figure 11.4 – Behavior of the rubbers when assumed to be linear or quadratic.

Figure 11.5 displays the forces as found in node C, D, and E for a rubber which acts linear (Fig. 11.5A) and a rubber that acts quadratic (Fig. 11.5B).

This information shows that the limiter puts a tilting force on the snowboard which results in a moment around the center line of the snowboard. A redesign should also allow to put a moment on the snowboard.
References


Appendix 12

Chairlifts configurations and dimensions
In this Appendix information can be found on chairlift terms, dimensions, and loading and unloading times.

**Definitions**

According to Wikipedia the term ski lift generally refers to any cable transport device that carries skiers up a hill [12.1]. Ski lifts can be found in many shapes and sizes, but they can all be brought back to three general types of ski lifts; Aerial lifts (Fig. 12.1), Surface lifts (Fig. 12.2), cable railways (Fig. 12.3). Aerial lifts include chairlifts, gondolas, and trams. Surface lifts transport skiers while their skis remain on the ground, like the T-bar lifts and J-bar lifts but also magic carpets. Cable railways transport skiers by railcar. [12.1]

Current companies that are making ski-lifts are POMA, Doppelmayr, and Leitner. Not too long ago Leitner and POMA joint forces, leaving only two main companies. Older companies were; CTEC, Hall ski-lift, Miner-denver, Partek, Ringer, and Tiegel [12.2][12.3][12.4].

This project focuses on chairlifts. Chairlift are available in numerous configurations. A chairlift, also known as a passenger ropeway, consists of a continuously circulating steel cable loop. It is strung between two end terminals and intermediate towers which carries a series of chairs. Depending on the size a passenger ropeway can move up to 4000 people per hour. Depending on the chairs chairlifts can seat 1, 2, 3, 4, 6, or 8 passengers. The fastest lifts achieve operating speeds of 12 m/s. Chairlifts can be divided into detachable chairlifts and fixed grip chairlifts. With fixed grip chairlifts each carrier is fastened to a fixed point on the rope. This means that all the chairs will move at the same pace, and if the chairs need to be slowed down to let someone on or off the entire lift needs to slow down. The detachable chairs detach the chairs from the loop in the loading and exiting station and can thus slow down the detached chairs and leave the rest running at a higher speed. The detachable chairs can be divided into two types with the first the chairs are slowed down in the loading and exiting station and in the second is called a carpet lift. In the carpet lifts the chairs move at full speed through the terminal and the snowboarding passengers are progressively accelerated on a system of conveyor belts, making the relative speed slower.

For safety reasons most chairs are equipped with a retention bar also called safety bar (Fig. 12.4). Like a seatbelt this bar is used to keep the passengers in their place. These safety bars are manually operated by the passengers and swung up and down to open en
close them respectively. Some safety bars are equipped with a footrest. The safety bar is convenient for the use of children and people who are unable to sit still, the footrest also reduced muscle fatigue from supporting the weight of a snowboard especially in long rides. A passenger sitting properly in a chairlift does not need a safety bar. From a purely physics point of view it can be seen that even in the event of a sudden stop the forces are taken care of by a smooth pivot motion of the gripper on the steel wire, the friction between the seat and the passenger would keep the passenger in the chairlift. However it is convenient when used with strong winds and when the chair is coated with ice.

The newer chairlifts are being fitted with a canopy, heated seats, and even an automatic safety-system that detects when the safety-bar cannot fully close and stops the system automatically when this happens (Fig. 12.5). [12.5-12.9]

**Dimensions**

RESNA standards were consulted to gain knowledge on chairlift dimensions as set in standards. Similar ISO standards were too expensive to acquire. The dimensions as found in the ANSI standard B77.1 from 2011 are displayed in Figure 12.6.

![Figure 12.6 - Chairlift dimensions as stated by ANSI standard B77.1 from 2011](image)

The only chairlift available in The Netherlands, can be found in Snowworld Landgraaf. This chairlift was measured during a visit (Fig. 12.7).
Figure 8.7 – All dimensions measured at a chairlift in Snowworld landgraaf
Loading and unloading times.

<table>
<thead>
<tr>
<th>Chairlift name</th>
<th>Youtube link</th>
<th>Loading (skidding) [sec]</th>
<th>Loading (safety bar) [sec]</th>
<th>Unloading [sec]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skippy (2009)</td>
<td><a href="http://www.youtube.com/watch?v=BQS9dmesuA">http://www.youtube.com/watch?v=BQS9dmesuA</a></td>
<td>12</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>Sesselbahnen</td>
<td><a href="http://www.youtube.com/watch?v=Hz3CiQz11jM">http://www.youtube.com/watch?v=Hz3CiQz11jM</a></td>
<td>10</td>
<td>x</td>
<td>6</td>
</tr>
<tr>
<td>Masnerkopbahn</td>
<td><a href="http://www.youtube.com/watch?v=ylIKq6S59XA">http://www.youtube.com/watch?v=ylIKq6S59XA</a></td>
<td>9</td>
<td>x</td>
<td>4</td>
</tr>
<tr>
<td>(NA)</td>
<td><a href="http://www.youtube.com/watch?v=wVGVhv1YBj_8">http://www.youtube.com/watch?v=wVGVhv1YBj_8</a></td>
<td>10</td>
<td>x</td>
<td>X</td>
</tr>
</tbody>
</table>

Average: 10.25 x 6.33

Table 12.1 – Chairlift loading and unloading times, including the average time taken over the four chairlifts

To keep the average chairlift loading and unloading times (Table 12.1) in mind this design could preferably load a chairlift in less than 10 seconds and unload a chairlift in less than six seconds.

References


Appendix 13

Chairlifts statistics
In this appendix statistics can be found on the information gathered from chairlifts available in 254 adaptive ski areas in America and Canada.

America and Canada have a total number of 254 adaptive ski areas. These areas are areas that have an adaptive program, which means a person with a handicap can take adaptive ski and/or snowboard lessons in these areas. Using www.skitown.com [13.1] these 254 areas were analyzed by comparing the number of runs, the number of lifts, and area height.

These areas have a total number of 12461 runs and a grand total of 2200 lifts, 1416 of these lifts are chairlifts. Per area there are 49 runs on average (st. dev. 40.35 runs), with an average of 5.7 chairlifts (st. dev. 4.19 chairlifts), which means that on average there are 0.15 chairlifts per run.

Figure 13.1 – Division of the type of lifts in percentages

Figure 13.1, shows the division of lifts in the areas. Of the 254 adaptive areas in America and Canada there are only 41 areas with less than 50% of chairlifts, just 11 have less than 33% chairlifts, and the area with the lowest percentage of chairlifts still has 1 chairlifts out of the 9 lifts available. 14 out of the 254 adaptive area’s in America and Canada only have chairlifts available. In the areas with less than 50% of chairlifts the chairlifts were often used for important connections in the area (10 different area maps were analyzed). Figure 13.2 and 13.3, show two maps of these type of areas, in these Figures it can be seen that the lifts that bring users all the way to the top are chairlifts. Those lifts allow users to connect mountain parts and get onto the other side of a mountain. The magic carpets and surface lifts often only allow users to get onto one trail.
Figure 13.2 – Map of a ski area

Figure 13.3 – Map of a ski area
Figure 13.4, shows the division of persons per chairlifts. This Figure shows that more than half of the chairlifts are either two or three person chairlifts. None of the 254 areas have any 8-person lifts.

References

Appendix 14

Using a Chairlift
In this Appendix information can be found on how (sit-)snowboarders use a chairlift.

Experience from snowboarders and multiple youtube movies [14.1][14.2][14.3][14.4][14.5][14.6][14.7][14.8] showed that for a snowboarder to get in and out of the chairlift there are multiple steps involved. The chairlift ride can be divided in three phases: 1) the loading phase, 2) the riding phase, 3) the unloading phase.

**The loading phase**

- Unstrap one of your boots from the snowboard and skate carefully to the chairlift gate. (This might mean stand in line)
- When it is your turn, go through the chairlift gate and skate until you are in line with the ‘load here’ sign.
- Point your snowboard forward. As the chairlift chair approaches, look behind you and sit down carefully on the chairlift chair in your designated spot.
- As the chairlift chair leaves the loading station, carefully lower the safety bar.

**The riding phase**

- Keep the center of mass (COM) above the chairlift seat to avoid tumbling out of the chairlift

**The unloading phase**

- As you approach the end of the chairlift, raise the safety bar.
- Make sure you keep the nose of your snowboard pointed slightly upwards.
- Place your snowboard flat on the snow and pointing forward. Stand up and place your back foot on the snowboard next to your back binding.
- Maintain a balanced body position. Look and point straight ahead. Then you will lose your speed on the flat area or make a slight J-turn to lose speed, and come to a stop.
- Re-strap your boot to the snowboard.

Using a chairlift with a sit-snowboard will involve similar steps excluding the unstrapping and re-Strapping of the one boot. The functionality of a sit-ski was taken as a standard for the new to be designed sit-snowboard, since these have shown to work on chairlifts and the user seems to be happy with the independent use of this product. A sit-skier does not stand in line, nor does he/she go through the chairlift gates since they can skip the line and enter from an alternative entrance also used by ski classes. Since MINI has been designed to be used with an instructor the sit-snowboard user can be aided in his/her movement to the chairlift by the instructor, which eliminates the design of a propulsion method. This leaves the main focus of this project on pointing the snowboard forward and maintaining a balanced body position. A propulsion method would be a nice bonus during this design since it does benefit the user’s independence.
References


Appendix 15

Edge Catching
In this Appendix terms and conditions of edge catching can be found, this is needed to understand the situation when unloading a chairlift with a (sit-)snowboard.

When catching an edge the (sit-)snowboarder is tripped up by the so called leading edge of the snowboard getting caught in the snow (Fig. 15.1). The sideways component of the (sit-)snowboarder’s velocity causes an edge to catch. Snow normally goes under the base of the snowboard before it meets an edge, if the snow meets the leading edge before it meets the base, the snow exerts a force on the outside of the edge (Fig. 15.1). This stops the snowboard from sliding and trips up the (sit-)snowboarder (Fig. 15.2). The forward velocity of the (sit-)snowboarder determines the impact velocity of the snowboarder (Fig. 15.3).

There are three reasons for the edge to catch; the angle of the slope changes, the angle of the snowboard changes, or the direction of the snowboard changes. A combination of these reasons is also possible.
In order to avoid edge catches there are three principles to keep in mind; clearance, sliding sideways, changing the edge. When the leading edge is kept clear of the snow an edge cannot catch. Greater clearance allows for some fluctuations in the slope angle to occur. When sliding sideways the leading edge will have a bigger spread (Fig. 15.4). In order to make this leading edge as small as possible going down a slope with the snowboard pointed down would be the best option. However when doing so the snowboarder will pick up speed. The last thing that will reduce the edge catching is for the snowboarder to commit to an edge. Definite actions cause predictable outcomes, looming in the middle of the snowboard will cause the snowboard to chatter (App. 10).

**References:**


Appendix 16
Excel Model
In this Appendix information can be found on the excel model made to verify the placement of the center of mass (COM).

Snowboarding has everything to do with the placement of the center of mass (COM) (App. 11). In order to verify and determine the placement of the COM, an excel-sheet was created. This excel sheet divides the human body in 8 parts with the accompanied nodes to connect these parts and to place the COM of each body part on a node.

![Figure 16.1 – Sit-snowboarder position in neutral position (Upper body in a vertical position)](image)

Table 16.1, shows the input cells of the excel-sheet. The weight is given in percentages, [16.1], so that the actual weight does not matter. In this case the decision was made to take the length of the body parts [16.2] and the placement of the COM [16.1] that was also used to define MINI. One can alter the “body” position of the model by changing the angles between the body parts, there is also an option of changing the angle in a body part. This option is not to be used in most body parts but was convenient in the angle of the back, since the lower back is very well capable of taking on a different angle than the upper back. When the position of the body is changed the red node, the COM of the entire body, will shift and the position of the overall COM will be determined (Fig. 16.1).
### References:


Appendix 17
Unloading Model
This appendix discusses a simplified model of the chairlift unloading phase created to analyze the maximum allowable, safe angle of exit of the snowboard.

To avoid catching an edge during the loading and unloading phase the snowboard needs to be close to parallel with the line of motion of the chairlift (Fig. 17.1). The 'angle of exit' ($\beta_{exit}$) is set as the angle of deviation of the snowboard from this line of motion. A simplified model of the sit-snowboard is created to determine the maximum allowable, safe angle of exit of the snowboard during unloading of the chairlift (Fig. 17.2, 17.3). The sit-snowboarder is modeled to catch an edge at unloading of the chairlift. In this model the sit-snowboarder and the snowboard are considered as one rigid body, modeled as an inverted pendulum, with the COM placed at a height ($z$) from the bottom of the snowboard. The snowboard is modeled parallel with the slope ($\alpha_s$) at the point of unloading (Fig. 17.2, 17.3). When the sit-snowboarder catches an edge the sit-snowboarder is modeled to pivot around the edge of the snowboard ($A$). During this pivoting motion the COM of the sit-snowboarder including the sit-snowboard will go from an initial height ($h_1$) to a maximum final height ($h_2$). If the motion continues beyond the final position the COM goes beyond the edge of the snowboard and the sit-snowboarder will tumble. To make sure that the sit-snowboarder will not tumble, the kinetic energy ($E_k$) that the sit-snowboarder and sit-snowboard possess at the start of the pivoting motion has to be equal or less to the amount of potential energy ($E_p$) that can be obtained with the height gain ($dh$) (Eq. 17.1, Fig. 17.2).

$$\sum E_1 = \sum E_2 \Rightarrow h_2 - h_1 = \frac{0.5 \cdot V_{lift}^2}{g}$$  \hspace{1cm} [Eq. 17.1]

$$h_x = (z + L \cdot \tan(\alpha_s)) \cdot \cos(\alpha_x)$$ \hspace{1cm} [Eq. 17.2]

$$\alpha_x = \tan^{-1}\left(\frac{L}{z}\right)$$ \hspace{1cm} [Eq. 17.3]

Where the distance $L$ is the distance (parallel with the line of motion) taken from the origin ($O$) of the snowboard to the edge of the snowboard (Fig. 17.3), $g$ is the gravitational acceleration, and $V_{lift}$ is the chairlift speed. This distance $L$ is directly related to the angle of exit (Eq. 17.4).

$$\beta_{exit} = \sin^{-1}\left(\frac{0.13}{L}\right)$$ \hspace{1cm} [Eq. 17.4]

Figure 17.1 – The exit angles of a (sit-)snowboarder. From a mathematical model (section 2.1.3) it was determined that a sit-snowboard should be kept within 8 degrees of the line of motion of the chairlift in order to prevent the user from tumbling over when exiting the chairlift, indicated by the striped area.

Figure 17.2 – Model of the sit-snowboard and sit-snowboarder at unloading the chairlift; $V_{lift}$ is the chairlift velocity, $z$ is the height of the COM measured form the snowboard, $\alpha$ is the angle of the snowboard measured from horizontal, $L$ is the distance from the center of the snowboard ($O$) to the edge of the snowboard ($A$), $h$ is the height of the COM measured from the snow, $dh$ is the difference in height between the black and grey image. The black image is at the moment of unloading, the grey image is right before the sit-snowboarder will tip over.
To simplify the snowboard it was modeled as being square (Fig. 17.4), this induces a maximum error of: $\frac{(L_{\text{max flat}} - L_{\text{max curved}})}{L_{\text{max curved}}} \times 100\% = 0.8\%$

To determine the safe angle of exit ($\beta_{\text{exit}}$) (the angle of exit with which the sit-snowboarder will not tumble) three values need to be determined: 1) the height of the COM ($z$), 2) the angle of the slope ($\alpha_i$), and 3) the chairlift speed ($V_{\text{lift}}$).

1) To determine the height of the COM the excel model (App. 16) was used with the following data:

<table>
<thead>
<tr>
<th>Body part</th>
<th>alpha [degrees]</th>
<th>$y$</th>
<th>$z$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foot</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>COM Foot</td>
<td>0</td>
<td>0</td>
<td>0.098</td>
</tr>
<tr>
<td>Calf</td>
<td>44</td>
<td>0.1837</td>
<td>0.2754</td>
</tr>
<tr>
<td>COM Calf</td>
<td>44</td>
<td>0.2920</td>
<td>0.3800</td>
</tr>
<tr>
<td>Thigh</td>
<td>21</td>
<td>-0.0163</td>
<td>0.4984</td>
</tr>
<tr>
<td>COM Thigh</td>
<td>21</td>
<td>-0.1990</td>
<td>0.5685</td>
</tr>
<tr>
<td>Trunk</td>
<td>34</td>
<td>-0.0423</td>
<td>0.8009</td>
</tr>
<tr>
<td>COM Trunk</td>
<td>34</td>
<td>0.05374</td>
<td>0.9433</td>
</tr>
<tr>
<td>Head</td>
<td>34</td>
<td>0.16214</td>
<td>1.1040</td>
</tr>
<tr>
<td>COM Head</td>
<td>34</td>
<td>0.25673</td>
<td>1.2442</td>
</tr>
<tr>
<td>Upper arm</td>
<td>-34</td>
<td>-0.0263</td>
<td>0.8246</td>
</tr>
<tr>
<td>COM Upper arm</td>
<td>-34</td>
<td>-0.1023</td>
<td>0.7120</td>
</tr>
<tr>
<td>Forearm</td>
<td>25</td>
<td>-0.0609</td>
<td>0.6232</td>
</tr>
<tr>
<td>COM Forearm</td>
<td>25</td>
<td>0.0038</td>
<td>0.4845</td>
</tr>
<tr>
<td>Hand</td>
<td>70</td>
<td>0.0356</td>
<td>0.4729</td>
</tr>
<tr>
<td>COM Hand</td>
<td>70</td>
<td>0.1805</td>
<td>0.4202</td>
</tr>
</tbody>
</table>

This represents the sit-snowboarder in a position which places the center of mass $y$-coordinate in the middle of the snowboard. The $z$-coordinate of the COM of the human body in this position can be calculated using the following equation:

$$z_{\text{body}} = \frac{\sum x_i w_i}{\sum w_i} = z_{\text{tot}} = 0.684 \text{ m} \quad [\text{eq. 17.5}]$$
Using the following information, the total center of mass can be determined:

<table>
<thead>
<tr>
<th>What</th>
<th>Weight [kg]</th>
<th>COM z-coordinate [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boarder</td>
<td>80 (max. Weight user)</td>
<td>0.684 (excel model)</td>
</tr>
<tr>
<td>Board</td>
<td>3 (weighted)</td>
<td>0.005 (estimated)</td>
</tr>
<tr>
<td>Construction</td>
<td>11 (weighted)</td>
<td>0.33 (estimated)</td>
</tr>
</tbody>
</table>

Table 17.2 – Data used to calculate the z-coordinate of the COM of the sit-snowboard and sit-snowboarder as one

COM z-coordinate of entire construction:

\[ z = z_{tot} = \frac{\sum z_i w_i}{\sum w_i} \Rightarrow z_{tot} = 0.62 \text{ m} \]  \hspace{1cm} [eq. 17.6]

2) To determine the angle of the slope (\( \alpha_1 \)) the angle of the slope at Snowworld Landgraaf was measured. This slope was tilted 5 degrees downward, with a safety factor of 3 this results in a 15 degree angle for the slope.

3) To determine the speed of a chairlift (\( V_{\text{lift}} \)) the track and trace data from a snowboarder can be analyzed (Fig. 17.5). Since fixed grip chairlift are will result in the fastest relative speed of the sit-snowboarder (App. 12) these chairlift were analyzed. The chairlift rides can be recognized by the raise in elevation and the close to constant speed, all chairlifts in this data were fixed grip chairlifts. This data shows maximum chairlift speeds of about 9 km/h = 2.5 m/s.

![Figure 17.5 – Track and trace data of a snowboarder](image)

Equations 17.1-17.3 can be combined to:

\[
\sum E_1 = \sum E_2 \Rightarrow h_2 - h_1 = \frac{0.5 v_{\text{lift}}^2}{g} \Rightarrow L^2 + z^2 - (z + L \cdot \tan(\alpha_1)) \cdot \cos(\alpha_1) = \frac{0.5 v_{\text{lift}}^2}{g} \Rightarrow
\]

\[
L^2 - L (\tan(\alpha_1) \cdot \cos(\alpha_1)) + z^2 - z \cdot \cos(\alpha_1) - \frac{0.5 v_{\text{lift}}^2}{g} = 0
\]

Knowing \( V_{\text{lift}} = 2.5 \text{ m/s} \), \( g = 9.81 \text{ m/s}^2 \), \( \alpha_1 = 15 \text{ degrees} \), and \( z = 0.62 \text{ m} \).

\[
L^2 - L (\tan(15) \cdot \cos(15)) + 0.62^2 - 0.62 \cdot \cos(15) - \frac{0.5 \cdot 2.5^2}{9.81} = 0 \Rightarrow
\]

\[
L^2 - 0.26L - 0.53 = 0
\]

Using the mathematical ABC-rule this gives; \( L = 0.87 \text{ m} \), with eq. 17.4 this means \( \beta_{\text{exit}} = 8.6 \text{ degrees} \). To make sure the sit-snowboarder will not tumble over the maximum angle of exit is therefore set at 8 degrees (Fig. 17.1).
Appendix 18
Design Specifications
In this Appendix information can be found on the design specifications created for the design challenge of this study.

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Based on</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. A person should be able to use the product without the use of the legs</td>
<td>[Prodaptive]</td>
</tr>
<tr>
<td>a. During use of the snowboard no active control of any of the leg and/or foot muscles may be required</td>
<td></td>
</tr>
<tr>
<td>2. The legs of the user should/must be restricted from moving around freely, only motions to facilitate the motion of the center of mass should be allowed</td>
<td>[sit-skiers experience and common sense; no control over legs, users do not know where their legs are in space and should not have to worry about that either]</td>
</tr>
<tr>
<td>3. The design should be able to function in snowboarding conditions (-20ºC to 10 ºC), including with snow that could jam the system</td>
<td>[18.1]</td>
</tr>
<tr>
<td>4. The user shall be kept in his/her sit-snowboard seat during the chairlift ride</td>
<td>[App. 19]</td>
</tr>
<tr>
<td>5. The design shall be able to be transported by a chairlift without altering the chairlift</td>
<td>[App. 19]</td>
</tr>
<tr>
<td>6. The user shall be able to use the sit-snowboard with the help of maximally one snowboard buddy</td>
<td>[current design does not work without the buddy]</td>
</tr>
<tr>
<td>a. This snowboard buddy can give a push or pull when needed</td>
<td>[current design]</td>
</tr>
<tr>
<td>b. This snowboard buddy will help the user to get up after a fall</td>
<td>[current design]</td>
</tr>
<tr>
<td>c. The buddy can help with chairlift use, there are three options:</td>
<td></td>
</tr>
<tr>
<td>i. If the design does not allow for the user to get in and out of the chairlift by him/herself the design can only take up one seat in the chairlift in order for the buddy to be able to sit next to the user.</td>
<td></td>
</tr>
<tr>
<td>ii. If the design will take up two seats in the chairlift and the user must be able to get into the chairlift autonomously, the buddy will then help with dismounting the chairlift</td>
<td></td>
</tr>
<tr>
<td>iii. If the design will take up two seats in the chairlift and the user must be able to get out of the chairlift autonomously, the buddy will then help with mounting the chairlift</td>
<td></td>
</tr>
<tr>
<td>7. The design should not occupy more than two seats in the chairlift, which means that a width of maximally 940 mm can be used</td>
<td>[App. 12]</td>
</tr>
<tr>
<td>8. The design should not hinder sit-snowboarding</td>
<td></td>
</tr>
<tr>
<td>a. The height of the sitting tube will be 665 mm or lower during the riding of the snowboard</td>
<td>[comments from users, App. 2]</td>
</tr>
<tr>
<td>b. The weight of the sit-snowboard including</td>
<td></td>
</tr>
</tbody>
</table>
snowboard should be less than 20 kg

<table>
<thead>
<tr>
<th>c. It should be possible to provide a force to the board to make it twist, without the use of the legs</th>
</tr>
</thead>
<tbody>
<tr>
<td>App. 2</td>
</tr>
<tr>
<td>[earlier prototypes and articles on snowboarding, no numbers are mentioned since the amount of twist that is desired depends on the user and the amount of twist made possible also depends on the snowboard used]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>d. The design should not hit the snow, in order to avoid this an angle of 40 degrees should be kept clear at all times</th>
</tr>
</thead>
<tbody>
<tr>
<td>App. 2</td>
</tr>
<tr>
<td>[earlier prototypes, App. 2]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>e. The design should be able to move the projection of the COM from heel- to toe-side over the total width of the snowboard, which will need a displacement of 270 mm this can be realized with a tilting motion of the pelvis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prodaptive</td>
</tr>
<tr>
<td>[Prodaptive]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>9. Sit-snowboarding should be done in a sideways position; the sit-snowboarder will sit with his/her nose pointing to the toe-side of the snowboard</th>
</tr>
</thead>
<tbody>
<tr>
<td>App. 9</td>
</tr>
<tr>
<td>[App. 9]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>10. Getting in and out of the lift should be done with the snowboard within 8 degrees or “in line” with the chairlift</th>
</tr>
</thead>
<tbody>
<tr>
<td>App. 17</td>
</tr>
<tr>
<td>[this to avoid catching an edge, App. 17]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>11. No loose attributes will be used for using the chairlift</th>
</tr>
</thead>
<tbody>
<tr>
<td>---</td>
</tr>
<tr>
<td>[practical consideration, loose]</td>
</tr>
</tbody>
</table>
12. It should be possible to apply a momentum to the board
   a. In the y-direction, on the edges of the board, in order to put the snowboard on its edge

13. The design should not use motions that are outside the range of motions listen in table 10.3.

<table>
<thead>
<tr>
<th>TABLE 10.3 Average Range of Motion (ROM) Values for Healthy Adults</th>
</tr>
</thead>
<tbody>
<tr>
<td>Joint</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>Shoulder</td>
</tr>
<tr>
<td>Extension</td>
</tr>
<tr>
<td>Abduction</td>
</tr>
<tr>
<td>Medial rotation</td>
</tr>
<tr>
<td>Latral rotation</td>
</tr>
<tr>
<td>Elbow</td>
</tr>
<tr>
<td>Flexion</td>
</tr>
<tr>
<td>Extension</td>
</tr>
<tr>
<td>Radicular</td>
</tr>
<tr>
<td>Pronation</td>
</tr>
<tr>
<td>Supination</td>
</tr>
<tr>
<td>Wrist</td>
</tr>
<tr>
<td>Extension</td>
</tr>
<tr>
<td>Radial deviation</td>
</tr>
<tr>
<td>Ulnar deviation</td>
</tr>
<tr>
<td>Carpal spine</td>
</tr>
<tr>
<td>Flexion</td>
</tr>
<tr>
<td>Extension</td>
</tr>
<tr>
<td>Lateral flexion</td>
</tr>
<tr>
<td>Rotation</td>
</tr>
</tbody>
</table>

Data from the American Academy of Orthopaedic Surgeons (Greene and Hedenskin 1994) and the American Medical Association (1988).

Wishes
1. The “baseplate” fits on a regular snowboard without making changes to the board
   a. The design will be able to be mounted with 16 or less m6 screws. The screws are divided into two groups of 8 or 6 with distance of 40-40 mm from one another, and a distance ranging from 390-420 mm between the two groups.

2. Mounting the chairlift should take less than 10 seconds
3. Dismounting the chairlift should take less than 6 seconds
<table>
<thead>
<tr>
<th>4. Mounting and dismounting can be done autonomously by the user</th>
<th>[App. 5, 9]</th>
</tr>
</thead>
<tbody>
<tr>
<td>5. The user will get constant feedback from the board about his/her position on the board</td>
<td>[“free” motion (floating) on the board was found to be confusing/frightful to the users, Prodaptive info]</td>
</tr>
<tr>
<td>14. It should be possible to apply a momentum to the board</td>
<td>[just like on a snowboard, to apply pressure on the nose/tail in order to gain control over the board motions, Prodaptive]</td>
</tr>
<tr>
<td>a. In the x-direction, which will be applied on the running length of the snowboard with exclusion of the piece of board in between the inserts (green area in figure), in order to control pressure on the boards nose/tail</td>
<td></td>
</tr>
</tbody>
</table>

---

**Recommendations**

| 6. Provide damping in up-/down-motion of the COM | [to enhance the comfort of riding, Prodaptive] |

---

**References:**

Appendix 19
Design Choices
In this Appendix the design choices made during the design process are described and analyzed.

**Preliminary design choices**

<table>
<thead>
<tr>
<th>Choice number</th>
<th>Choice</th>
<th>Reasoning</th>
</tr>
</thead>
</table>
| 1             | Don’t change the composition of the chairlift                          | • The cost and time investment is high
• The user will be dependent on the chairlift available |
| 2             | The sit-snowboard design incorporates the use of widely available snowboards, used for regular snowboarding | • This allows the user to choose his/her own snowboard
• This means that no actual snowboard needs to be designed |
| 3             | Create two use modes: 1) a snowboarding mode, and 2) a chairlift mode  | • Easy entering and exiting of the chairlift
• Easier to comply with the design requirements |

If this project would focus on changing the chairlift composition the sit-snowboarder would be dependent on the chairlift available in a certain area. This means that the user cannot choose the ski-area based on other factors than; “are their chairlifts available that I can maneuver?” This would be limiting to the user and is unnecessary. The other part of this design decision is the cost and time investment, to change all chairlift into the adaptive chairlift that could be used by the sit-snowboarder would cost a lot of money and time.

A snowboarder decides on a snowboard type based on experience, rider abilities, and the desire to ride specific slopes (App. 10). In order to provide a sit-snowboard with the same choices in snowboards the use of a regular and widely available snowboard is desired. This also means that no snowboard needs to be designed which determines a boundary of this design assignment.

The snowboarding mode allows for a sideways position, and the chairlift mode allows a longitudinally in the direction of the chairlift motion. This makes it easier for the design to comply with the design requirement of fitting on one chair in the chairlift and the position of the board at entering and exiting (App.18).

![Figure 19.1 - Two different use modes; A) shows the snowboarding mode in which a sit-snowboarder can sit-snowboard, and B) shows the chairlift mode which allows the sit-snowboarder to use the chairlift](image_url)

<table>
<thead>
<tr>
<th>Choice number</th>
<th>Choice</th>
<th>Reasoning</th>
</tr>
</thead>
</table>
| 4             | Sit-snowboard seat will sit on a chairlift chair                       | • Feels safer
• More social |

When the user sits in the sit-snowboard seat it feels safer to put that seat on one of the chairlift chairs. This is also beneficial for the social aspect of the chairlift ride (App.14).
Making everything mechanical eliminates the complications found with electrical equipment in the snow, it means that the user can determine the action radius of the product as opposed to the battery of the product. Making everything mechanical also eliminates complications found with pneumatics, like; difficulty in fluid choice due to temperature differences and changes, and fluid leakage. The user also mentioned feeling like a cheater when using something non-mechanical (App. 5), with external power, which is another reason to go with a mechanical design.

Turning to change the position between rider and chairlift position allows for the user maintain a balance body position, which benefits the loading and unloading of the chairlift. It also allows for a mechanism that allows the user to change his/her own position as opposed to letting someone else help the user with this. It makes it possible to take up only one seat in the chairlift (App. 18).

Detaching the handlebars allows for the user to use these handlebars as a mechanism for propulsion, balance, and stabilization during loading and unloading of the chairlift which all benefits the user's independence. It makes sure that the seat can sit on a chair without hitting the handlebar.

### Design choices during design phase

<table>
<thead>
<tr>
<th>Choice number</th>
<th>Choice</th>
<th>Reasoning</th>
</tr>
</thead>
</table>
| 1             | Limiters | • Time efficient  
               |         | • Proven concept |

The limiters are not changed in shape from the limiters used in MINI, they were however changed in thickness to make sure they would not break during use in the new prototype. The reason the shape wasn’t changed was that it had proven it concept and did not require any change to fit in the new construction, which made it time efficient to maintain it.

| 2             | Handlebars | • Time efficient  
               |         | • Proven concept |

The handlebars are not changed in shape from the handlebars used in MINI, they were however changed in attachment to make them detachable in the new prototype. The reason the shape wasn’t changed was that it had proven it concept and did not require any change to fit in the new construction, which made it time efficient to maintain it.
The seat and knee pads were not changed from the seat and knee pads used in MINI. The reason was that they had proven their concept and did not require any changes to fit into the new construction, which made it time efficient to maintain them.

The sitting on one pole makes it easy to turn the position since it has only one center of rotation, it allows for the knees and feet to turn with the user making it very easy and comfortable to use since the user does not have to unstrap or reposition his/her legs. It does however make it relatively hard for users to get into the construction, but allows a user to stay in the construction for the remainder of the snowboard session. Sitting on one pole also allows the bearing to be on the top of the construction, which results in lower moments on the bearing and thus a smaller bearing.

Using bended tubes for the seat construction made this construction relative expensive (welded tubing was an alternative). However, welding or other type of connections would have made this design clumsy and relatively heavy. The use of bended tubes also makes the design look better and has makes this a clean construction meaning that clothing or skin cannot easily be torn by edges of the construction.

The reason to use a bicycle break handle in this concept was that it is easy to get, since every bicycle store has it. The fact that every bicycle store has a bicycle brake is also convenient since most wintersport areas have a bicycle store due to the fact that these areas are mountain bike areas in summer. The bicycle brake is also easy to use, since most people have use them before.
Appendix 20

Forces on Frame
In this Appendix information can be found on the forces acting on the sit-snowboard during use. These forces were calculated since they are not known from measurements.

**Falling**

Falling produces different forces on the construction and the falling process should therefore be analyzed. Using video images of crashes with MINI the point of impact can be determined.

The falls have been analyzed using two groups; forward and backward falls.

![Figure 20.1 – Examples of landings of forward falls with MINI](image)

Using video footage 5 forward falls were analyzed (Fig. 20.1). From these images it can be concluded that if a user falls forward the point of impact can either be found on the knees or divided over the front side of the handlebars.

![Figure 20.2 – Examples of landings of backward falls with MINI](image)

Using video footage 9 backward falls were analyzed (Fig. 20.2). From these images it can be concluded that if a user falls backward the point of impact can be found on the seat or sitting tubing of the construction.

In order to calculate the forces on the frame during falling some assumptions had to be made.

**Assumptions:**

- When the sit-snowboarder hits the snow he/she will instantly stop any former motions (worst case)
- The speed at impact is the speed that forces a snowboarder towards the snow (worst case, Fig. 20.3)
The maximum speed of the prototype will be 30 km/h which is 8.33 m/s [Gina van der Werf, Proactive, personal communication, August, 2013]. When falling the boarder will gain some speed, due to the gravitational energy from the height loss (Fig. 20.3, eq.20.1) [20.2]. Like seen during the video analysis of falling the knees, buttocks or handlebar will hit the snow first.

\[ \sum E_1 = \sum E_2 \Rightarrow 0.5 \cdot m \cdot v_1^2 + m \cdot g \cdot h_1 = 0.5 \cdot m \cdot v_2^2 \]  

Turning every speed into a height with \( h = \frac{0.5 \cdot v^2}{g} \), the speed can be compared to a paper found on the 8 meter jump with a snowboard [20.2] The highest impact speed can be found on the highest point of the sit-snowboard construction which can be found on the handlebar. The highest point of the handlebar is at \( h = 0.93 \) m, on impact this results in a speed of 9.36 m/s, which can be compared to falling from a height of 4.47 m.

A fall from 8 meter will result in a force of 5 times body weight on the snowboard [20.2]. From this it can be assumed that 3 times body weight during a crash allows for a safe estimation.

\[ F_{fall} = \text{roundup}(3 \cdot m \cdot g) \Rightarrow F_{fall} = 2355 \text{ N} \]  

When the sit-snowboarder falls the forces on the knees and buttocks will only compress the tubing, however when these forces are absorbed by the handlebars they will cause a moment on the bottom of the handlebars (Fig. 20.4).
Forces due to bump

When sit-snowboarding bumps can be hit, since even a nicely trimmed slope does not have a flat surface. When the boarder goes over a bump the force on the snowboard will increase, due to the gravitational energy depending on the height of the bump. The snow (depending on the amount and snow condition), snowboard (depending on the direction) and construction (depending on the amount and direction of the force) will absorb some of this energy, leaving a lot of unknowns in this situation. Since this design assignment should maintain the functionality of MINI the new design will be tested with the same amount of forces that MINI was calculated with. In order to take the bumps and crashes into account MINI was tested with 1.5 times the body weight, which means the structure should withstand the following amount of force:

\[ F_{\text{bump}} = \text{round up} (1.5 \times m \times g) = \Rightarrow F_{\text{bump}} = 1178 \, N \]  \hspace{1cm} \text{[eq. 20.3]}

A study showed that a snowboarder making an 8 meter jump will end up with 5 times his body weight on the snowboard at landing \[20.2\]. These forces were recorded using a force plate and an insole measurement system, and represent the normal force on the board. Since the sit-snowboard is not going to make any jumps of that kind (0.4 m or less \[Gina van der Werf, Prodaptive, personal communication, August, 2013\]). This makes the force of 1.5 times bodyweight limit used in these measurements seem plausible.

Forces due to arm power

From different sources found data on maximum arm/hand power was collected (Table 20.1).

<table>
<thead>
<tr>
<th>Source</th>
<th>Condition</th>
<th>Force [N]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ay, H., et al., &quot;Biodynamic modeling and physical capacity assessment of human arm response in experienced torque tool operators&quot;, ASB, 2010</td>
<td>measured and calculated peak handle forces</td>
<td>63.09 N and 66.77 N</td>
</tr>
<tr>
<td>Badi, T.H., Boushaala, A.A., &quot;Effect of one-handed pushing and pulling strength at different handle heights in vertical direction&quot;, World Academy of science, Engineering and Technology, 2008, Vol. 23, p 375-378</td>
<td>8 men were measured, they had an average force of 53.83 lb en sd van 19.79 lb so highest pushing strenght of 53.83+3*19.79=113.2lb which is 51.35 kg</td>
<td>503.7N</td>
</tr>
<tr>
<td>Human strength data tables [Web page], [cited 07-2013], available from <a href="http://www.theergonomicscenter.com">http://www.theergonomicscenter.com</a></td>
<td>Maximum push 88+3<em>30=178 lb =&gt; 80.74 kg, maximum pull 94+3</em>34=196 lb =&gt; 88.9kg, Sitting 60 degree angle pulling force: 329 lb =&gt; 149.23 kg</td>
<td>Push 792 N Pull 872.1 N Sitting 1463.94 N</td>
</tr>
<tr>
<td>Canadian center for occupational health and safety [Web page], [cited 07-2013], available from <a href="http://www.ccohs.ca/oshanswers/ergonomics/push1.html">http://www.ccohs.ca/oshanswers/ergonomics/push1.html</a></td>
<td>Where a worker can support his body (or feet) against a firm structure higher forces can be developed</td>
<td>675 N</td>
</tr>
<tr>
<td>DINED [Web page], [cited 07-2013], available from <a href="http://dined.io.tudelft.nl/dined/full">http://dined.io.tudelft.nl/dined/full</a></td>
<td>measurement 59; pulling force 1 hand: &gt;99.99% measurement</td>
<td>641 N</td>
</tr>
<tr>
<td>NASA [Web page], [cited 07-2013], available from <a href="http://msis.jsc.nasa.gov/sections/section04.htm#_4.9_STRENGTH">http://msis.jsc.nasa.gov/sections/section04.htm#_4.9_STRENGTH</a></td>
<td>figure 4.9.3-6 maximal static push forces: preferred hand (max)</td>
<td>520 N</td>
</tr>
</tbody>
</table>

Table 20.1 – Maximum arm/hand forces of a human body
Looking at these forces it can be seen that the values from the ergonomics center are far from the other values, which makes it seem like they measured a different force. The highest value after the ergonomics center is coming from the Canadian center for occupational health and safety: this is a maximum force of 675 N. Using a safety factor of 1.5, the maximum force on the handlebars will be $F_{\text{hand}} = 1013 \text{ N}$. This seems a plausible force since a human wrist will break with an amount of force between the 1700-2000 N, [20.3], and when the force is generated by a human arm on the sit-snowboard part of the force is absorbed by the glove around the hand.

**Conclusions**

All the forces that can be found on both the sitting construction and the handlebar can be seen in Figure 20.5.

References


Appendix 21

Seat Design
In this Appendix information can be found on the design of the seat bearing and locking mechanism. Starting off with the design choices and followed by calculations needed to determine the dimensions of the mechanism.

It was decided that the snowboard needs to switch between two use modes (App. 19) this can be done in multiple ways; rotating the position, folding sitting tubes, translating the position (Table 21.1).

<table>
<thead>
<tr>
<th>Rotating position</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Diagram" /></td>
</tr>
<tr>
<td>Folding sitting tubes</td>
</tr>
<tr>
<td><img src="image2" alt="Diagram" /></td>
</tr>
<tr>
<td>Translating position</td>
</tr>
<tr>
<td><img src="image3" alt="Diagram" /></td>
</tr>
</tbody>
</table>

Table 21.1 – Different design options for the sit-snowboard seat

It was chosen to use the center rotating position to change the position between snowboarding and chairlift mode. The center rotation allows for the user maintain a balance body position, which benefits the loading and unloading of the chairlift. It also provides the opportunity for the user to take up only one seat in the chairlift chair, whilst most of the other options take up more space.
Concepts locking mechanism for seat position
Since rotating the seat should be voluntarily only, it is important to be able to securely lock the rotating mechanism whenever the user does not intend to rotate. This section describes some of the mechanism considered in this study.

Figure 21.1 – Seat locking mechanism. A) The locking mechanism is in the locked position, the spring holds the pin in position and the pin can be pulled up by the user, B) The locking mechanism is loose and the seat construction can be turned, once a hole has been reached the spring will push the pin down into the hole.

**Concept 1: Pin**
The Pin concept (Fig. 21.1) consists of a pin which will run through two aluminum plates in the locked position. The pin can be pulled up to take it out of the bottom aluminum plate in the unlocked position, then when the user turns between use modes the pin will be pushed into a second hole (chairlift mode) by a spring.

*Ease of use; Number of proceedings*
Lock: x (0)
Un-lock: lift pin (1)
Total: 1

*Ease of use; Difficulty of proceedings*
Although the user cannot see the holes that does not matter. The user only needs to know how to pull on the pin out and once the user is turning into position the pin will find itself into the hole due to the spring.

Degree of difficulty: +2

*Standardization*
The pin is standard and the other parts only need holes, this mechanism is therefore easy to create.

**Standardization:** +2

*Robustness; Snow-proof*
The only part that might have difficulty with the snow is the spring, but it will most likely work since the spring is fairly big, and bigger springs can also be found on sit-ski’s.

**Robustness:** +2

Force calculations
The force needed to operate the pin depends on the friction the pin will have in the holes and the spring stiffness of the spring used to keep the pin in place, if the proper spring is chosen this will result in little effort from the user.
**Concept 2: Screw**
The Screw concept (Fig. 21.2) consists of a pin is equipped with a thread which can be screwed into the sitting tube, this is the locked position. By unscrewing the pin the mechanism will be unlocked and the seat can be turned.

*Ease of use; Number of proceedings*
- **Lock**: push and twist (2)
- **Un-lock**: twist and pull (2)
- **Total**: 4

*Ease of use; Difficulty of proceedings*
This mechanism is quite easy to operate the only difficulty is the fact that the user cannot see the pin which makes it harder to screw the pin in and out. It is not that difficult however if a screw gets put into a hole in a tilted position it might not go in or worse; it might get stuck.

**Degree of difficulty**: +1

*Standardization*
All parts are quite standard. The only thing is that it needs to be put into the sitting tube which makes it a matter of tapping a screw hole into the sitting tube.

**Standardization**: +1

*Robustness; Snow-proof*
The hole in the sitting tube which needs to hold the pin might clog up with snow making it impossible to screw the pin in.

**Robustness**: -1

*Force calculations*
The force needed to operate the pin depends on the friction the pin will have in the holes.

**Concept 3: Clamp**
The idea of the Clamp concept (Fig. 21.3) is that the sitting tube has a square on it the clamp will then restrict it from turning since it is shape locked. When the clamp is shifted away from the square it can freely move, this is the unlocked position.

*Ease of use; Number of proceedings*
- **Lock**: press clamp (1)
- **Un-lock**: take clamp off (1)
- **Total**: 2

*Figure 21.3 – The Clamp concept for the locking mechanism of the seat mechanism.*
Ease of use; Difficulty of proceedings
Both proceedings are very easy to do, the only thing that might make it slightly difficult is the fact that the user needs to operate a clamp underneath the bottom of the seat which makes it hard to see.

Degree of difficulty: +1

Standardization
Although this mechanism cannot be bought off the shelves it is easy to make.

Standardization: +1

Robustness; Snow-proof
This mechanism seems robust however if snow gets caught in the mechanisms it is hard to operate it since it cannot get out of the system. Furthermore due to the vibrations the system might come loose during use.

Robustness: -2

Force calculations
The only force that the user needs to overcome is the friction force, this can be kept to a minimum.

Concept 4: Handle
The Handle concept (Fig.21.4) works just like the clips found in a folding bicycle. When the handle is in an unlocked position it will just dangle, then when the user pushes the handle through a hole in an aluminum plate the pin can be twisted 90 degrees which locks the system.

Ease of use; Number of proceedings
Lock: fold clamp, twist to tighten, fold handle (3)
Un-lock: lift handle, untighten, unfold clamp (3)
Total: 6

Ease of use; Difficulty of proceedings
In relation to other locking mechanisms the difficulty of the proceedings is very high. The user cannot see what he/she is doing but needs to be able to lock the clamp into place and twist it to secure the handle.

Degree of difficulty: -2

Standardization
The parts are very standardized and can be bought off the shelf, these clamps can be found in a foldable bicycle.

Standardization: +2

Robustness; Snow-proof
This handle can deal with quite a bit, this can be seen in the use of foldable bicycles, however dealing with a lot of snow might cause the system to jam.

Robustness: -1
**Force calculations**

Since it works in foldable bicycles and nearly everyone can operate it can be said that this mechanism can be operated.

**CONCLUSION:**

<table>
<thead>
<tr>
<th>LOCKING MECHANISM SEAT</th>
<th>Pin</th>
<th>Screw</th>
<th>Clamp</th>
<th>Handle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concepts:</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ease of use; number of proceedings</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Ease of use; difficulty of proceedings</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Standardization of parts</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Robustness; snow-proof</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Force calculations</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 21.1 – Harris profile of the locking mechanisms for the seat

From this chart (Table 21.1) it can be seen that the Pin concept will be a good option. Even though the concept Screw and Clamp also seems like a viable solution these concepts were not chosen due to the lack of robustness.

**Calculations**

**Bearing**

To design the bearing the maximum amount of force that this bearing has to deal with has to be calculated (Table 21.2) (Fig. 20.5A).

\[ M_x = 0 \text{ Nm} \]

\[ M_y = F_{\text{bump}} \times \text{length till knees} = 1178 \times 0.29 = 342 \text{ Nm} \]

\[ M_z = F_{\text{hand}} \times 2 \times \text{distance center snowboard to handlebar} = 1013 \times 2 \times 0.33 = 669 \text{ Nm} \]

**Summarized:**

<table>
<thead>
<tr>
<th>Direction</th>
<th>Force [N]</th>
<th>Moment [Nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>( F_{\text{alt}} = 2355 )</td>
<td>0</td>
</tr>
<tr>
<td>Y</td>
<td>0</td>
<td>342</td>
</tr>
<tr>
<td>Z</td>
<td>( F_{\text{bump}} = 1178 )</td>
<td>669</td>
</tr>
</tbody>
</table>

Table 21.2 – Forces and moments on bearing

A known bearing manufacturer, Igus [21.1], has a bearing made out of POM that can withstand these forces, it was decided to create this bearing using the same sizes (Fig. 21.5); \( d_1 = 50 \text{ mm} \), \( d_2 = 55 \text{ mm} \), \( d_3 = 63 \text{ mm} \), \( b_1 = 50 \text{ mm} \), and \( b_2 = 2 \text{ mm} \).
Locking pin
In order to keep the dimensions small it was decided to make the locking pin out of stainless steel (Table 21.3) [25.2-25.6].

<table>
<thead>
<tr>
<th>Stainless steel</th>
<th>Density:</th>
<th>$\rho = 8 \text{ g/cm}^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young’s Modulus:</td>
<td>$E = 68.9 \text{ GPa}$</td>
<td></td>
</tr>
<tr>
<td>Ultimate Tensile Strength:</td>
<td>$\sigma_t = 505 \text{ MPa}$</td>
<td></td>
</tr>
<tr>
<td>Tensile Yield (plastic deformation) Strength:</td>
<td>$\sigma_y = 215 \text{ MPa}$</td>
<td></td>
</tr>
<tr>
<td>Shear Modulus:</td>
<td>$G = 86 \text{ GPa}$</td>
<td></td>
</tr>
<tr>
<td>Shear Strength:</td>
<td>$\tau = 225 \text{ MPa}$</td>
<td></td>
</tr>
<tr>
<td>Poisson’s Ratio:</td>
<td>$\nu = 0.29$</td>
<td></td>
</tr>
</tbody>
</table>

Table 21.3 – Material properties for stainless steel

The maximum force on the locking pin is generated by the maximum Moment in Z-direction on the bearing; 669 Nm. Since the pin will be 0.1 m from the center of the bearing the maximum force on this pin will be $F = \frac{669}{0.1} = 6690 \text{ N}$.

With a solid stainless steel pin this will result in a dimension of:

$$\tau = \frac{4}{3} \times \frac{K_A \times \tau^*}{2 \pi d} \quad \text{(25.2)}$$

$\tau_{\text{max}}$ The maximum shear stress  
$K_A$ Service factor  
A Surface area of pin  
$$\frac{4}{3} \times \frac{2 \times 6690}{2 \times 0.25 \times \pi \times d^2} = 225 \text{ MPa} => d = 0.013 \text{ m}$$

To make this a more standard size it was chosen to make the pins 15 mm.

References


Appendix 22

Chairlift position
In this Appendix information can be found on the position of both the user and SnowGo in the chairlift.

**Chairlift position:**
In order not to fall off the chairlift chair the projection of the COM needs to be on the chairlift chair at all times. The excel sheet (App. 16) of the human being was used to check the position of the COM in the sit-snowboard position.

In the chairlift chair the COM should be placed as far back as possible. The buttocks will be moved all the way to the back of the sit-snowboard seat. The length of the thigh has been lengthened to 0.65 m for this situation. Lengthening the thigh enables this model to place the COM of the trunk to be placed on the sit-snowboard seat and in the meantime keep the COM of the legs as far forward as they could possibly be. The length of the thigh in this situation is rather high which means that in real life the COM projection would come further back due to repositioning of the legs. The knees have not been placed further back in this simulation since placing the knees in the knee pads brings the COM of the legs as far forward as possible creating the worst case scenario. This position is characterized with a lower back that will be tilted towards the chairlift chair backing (Fig. 22.1). In this case the COM is $y = -0.30$ m.

![Figure 22.1 - The sit-snowboader in a chairlift position, the back has been arched back towards the chairlift chair backing](image)

If in the same seated position we would start to move the upper body forward.
In this position, trunk and head are vertical, the COM is $y=-0.216$ m so 21 cm behind the center of the snowboard. This trunk and head position is a rather comfortable position [22.1]. All this information seems to show that the sit-snowboarder will be safe within the chairlift as long as the chairlift will come into the construction to at least 21 cm behind the center of the snowboard. For safety reasons it was decided that the chairlift should come into the structure to at least 10 cm behind the center of the snowboard. With the lengthened thigh this results in an upper body tilt angle of approximately 31 degrees. And with a p50 [22.2] thigh length this results in an upper body tilt angle of 5 degrees.

![Highback](image1)

Figure 22.3 – A highback

![Sideview of a chairlift seat](image2)

Figure 22.4 – Sideview of a chairlift seat; $z=0.21+\sin(15^\circ) \times y$

In order to get this far into the structure a space needs to be kept clear, based on both sit-ski’s and chairlift seat specs a height of 0.55 should be kept as the maximum height of a chairlift seat (App. 18, 19). So everything that should be on the chairlift seat has to be above that height. A chairlift sometimes hits a snowboarders highback (Fig. 22.3) [Gina van der Werf, Prodaptive, personal communication, July, 2013]. Based on this knowledge a research was done. Based on the height of the highback in the folded and upright position and the height of sit-ski’s it was decided that everything above 0.21 m should be kept clear too. So in between 0.21 and 0.55 the chairlift needs to be kept clear of legs, feet, and structures of any kind.

References


Appendix 23

Sitting Construction Design
In this Appendix information can be found on the design of the sitting construction. Starting off with the design choices and followed by calculations needed to determine the dimensions of the construction.

The seat needs to be able to shift the COM from one edge to the other, in order to do so a translation of the COM is needed. If this translation is accompanied by a rotation, like MINI, that does not matter (Fig. 23.1). A rotation of sitting construction is needed to allow a snowboarding mode and a chairlift mode.

Figure 23.1 – DOF's of seat construction (App. 18)
The sitting construction/tubing will be the connection between the seat, kneepads, and foot straps. Multiple configurations of the sitting tubes were analyzed.

The shape of the sitting tubes need to allow a chairlift to get underneath the sit-snowboard seat (App. 19, 22), concept (1), (4), (5), (8), (9), (11), and (15) are therefore dismissed.

It was decided to place the seat bearing as high as possible to limit the moments on the bearing and thus be able to use a smaller/lighter bearing. The following frameworks were designed with this in mind.

Design (A) was chosen since it allows the bearing to be placed close to the seat, which is considered as high as possible, and it creates the most direct (straight line) connection between the snowboard and the sitting construction. This direct connection means that the material needed for the connection will be kept to a minimum and that the moments
and forces on the connection will be less complex than the bends and curves in concept
(B) and (C). The bends and curves in those concepts cause high stresses at those specific
points.

Calculations
Tube diameters
The tube diameters will differ in the different part of the frame. The frame has been
divided into four parts/tubes (Fig. 23.2); Sitting tube, Horizontal tube, Vertical tube,
Knee bar. The maximum forces and moments on all those tubes will be analyzed and the
desired tube diameters and wall thicknesses will be calculated.

All these tubes will be made out of the same aluminum, 6061 Alloy, as MINI was made
out off. This alloy has the material properties found in Table 23.1 [23.1].

<table>
<thead>
<tr>
<th>Aluminum 6061 Alloy</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Density:</strong></td>
</tr>
<tr>
<td><strong>Young's Modulus:</strong></td>
</tr>
<tr>
<td><strong>Ultimate Tensile Strength:</strong></td>
</tr>
<tr>
<td><strong>Strength:</strong></td>
</tr>
<tr>
<td><strong>Shear Modulus:</strong></td>
</tr>
<tr>
<td><strong>Shear Strength:</strong></td>
</tr>
<tr>
<td><strong>Poisson's Ratio:</strong></td>
</tr>
<tr>
<td><strong>Table 23.1 – Material properties for Aluminum 6061 alloy</strong></td>
</tr>
</tbody>
</table>

The frame will be made of cylindric supporting shafts, Roloff Matek provides equations for
these shafts to calculate the desired diameter and wall thickness of the tubes [23.2].
For the maximum moments

For the maximum bending moment:

\[ d_a \geq \frac{3(32+M)}{\pi(1-k^4)\bar{\sigma}_b} \approx 2.17 \times \frac{3M}{(1-k^4)\bar{\sigma}_b} \] [23.2] \hspace{1cm} \text{[eq. 23.1]}

\begin{align*}
M & \quad \text{Maximum bending moment} \\
k & \quad \text{Diameter ratio, } k = \frac{d_i}{d_a} \text{ with } d_i \text{ as the inner diameter of the shaft, and } d_a \text{ as the outer diameter of the shaft} \\
\bar{\sigma}_b & \quad \text{Allowable bending stress, } \bar{\sigma} = \frac{\sigma}{S_{\text{min}}} \text{ } S_{\text{min}} = 3 \text{ will be used for the dynamic behavior in this prototype}
\end{align*}

For the maximum torsional moment:

\[ d_a \geq \frac{16+T}{\pi(1-k^4)\bar{\tau}_t} \approx 1.72 \times \frac{T}{(1-k^4)\bar{\tau}_t} \] [23.2] \hspace{1cm} \text{[eq. 23.2]}

\begin{align*}
T & \quad \text{Maximum torsional moment} \\
k & \quad \text{Diameter ratio, } k = \frac{d_i}{d_a} \text{ with } d_i \text{ as the inner diameter of the shaft, and } d_a \text{ as the outer diameter of the shaft} \\
\bar{\tau}_t & \quad \text{Allowable shear stress, } \bar{\tau} = \frac{\tau}{S_{\text{min}}} \text{ } S_{\text{min}} = 3 \text{ will be used for the dynamic behavior in this prototype}
\end{align*}

If not otherwise stated a k value of \( k = \frac{19}{25} = 0.76 \) is used which is the same value as used in MINI.

For the maximum forces

Pressing and pulling forces respectively; \( \sigma_d = \frac{F_d}{A} \) and \( \sigma_t = \frac{F_t}{A} \) [23.2] \hspace{1cm} \text{[eq. 23.3]}

For the shear forces: \( \tau_{sm} = \frac{F_s}{A} \) [23.2] \hspace{1cm} \text{[eq. 23.4]}

With \( A = 0.25 \times \pi \times (d_a^2 - d_i^2) \) [23.2] \hspace{1cm} \text{[eq. 23.5]}

In this section all the forces and moments are normalized to the forces and moments seen in Figure 23.4, with \( M_z \) = the torsional moment, \( M_x \) and \( M_y \) are the bending moments, and \( F_x \) = the pulling and \( F_z \) are the pressing forces, \( F_x \) and \( F_y \) are the shear forces.

The interplay of forces on the construction are a complicated, assumptions are done to be able to calculate the dimensions of the construction:

- Only one force will work on the construction at once
- All tubes are rigidly connected to one another
- The forces provided by the sit-snowboarders hand to the handlebars only influence the handlebars, and the bearing, the vertical tube, and the horizontal tubes. This means that it has no influence on the sitting tube and knee bar, which was done since the exact forces on these tubes are hard to determine.
- When the sit-snowboarder falls the forces will either be concentrated on the knee bar or on the sitting tube
- The falling force, \( F_{\text{fall}} \), does not produce a moment on the tubing (App. 20).
Sitting tube

From the forces on the sitting tube (Fig. 23.3) the moments on the sitting tube can be determined.

\[ M_x = 0 \text{ Nm} \]

\[ M_y = F_{\text{bump}} \times 0.5 \times \text{tube length} = 0.5 \times 1178 \times 0.15 = 89 \text{ Nm} \]

\[ M_z = 0 \text{ Nm} \]

**Summarized forces and moments:**

<table>
<thead>
<tr>
<th>Direction</th>
<th>Force [N]</th>
<th>Moment [Nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>( F_{\text{bump}} = 1178 )</td>
<td>0</td>
</tr>
<tr>
<td>Y</td>
<td>( F_{\text{fall}} = 2355 )</td>
<td>89</td>
</tr>
<tr>
<td>Z</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Knowing the maximum forces and bending moments the desired tube diameter for the sitting tube can be calculated. Using eq. 23.1-23.5:

- **Sitting tube**
  - \( da \) [mm]: 24
  - \( di \) [mm]: 18
  - Wall thickness [mm]: 3
  - Min \( \tau \) [MPa]: 11.9
  - Min \( \sigma \) [MPa]: 0

Aluminiumopmaat.nl has a tube with the following dimensions: 25x3 mm [23.3].

Horizontal tubes

From the forces on the horizontal tubes (Fig. 23.3) the moments on the horizontal tubes can be determined.

\[ M_x = 0 \text{ Nm} \]

\[ M_y = F_{\text{bump}} \times \text{length till knees} = 1178 \times 0.29 = 342 \text{ Nm} \]

\[ M_z = F_{\text{bump}} \times 0.5 \times \text{knee bar} = 1178 \times 0.5 \times 0.26 = 154 \text{ Nm} \]

**Summarized:**

<table>
<thead>
<tr>
<th>Direction</th>
<th>Force [N]</th>
<th>Moment [Nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>( F_{\text{bump}} = 1178 )</td>
<td>0</td>
</tr>
<tr>
<td>Y</td>
<td>0</td>
<td>342</td>
</tr>
<tr>
<td>Z</td>
<td>( F_{\text{fall}} = 2355 )</td>
<td>154</td>
</tr>
</tbody>
</table>

In this configuration there will be two tubes, which means that the tubes will only need to hold half of the forces and moments. Half the forces and bending moments will be:

<table>
<thead>
<tr>
<th>Direction</th>
<th>Force [N]</th>
<th>Moment [Nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>589</td>
<td>0</td>
</tr>
<tr>
<td>y</td>
<td>0</td>
<td>171</td>
</tr>
<tr>
<td>z</td>
<td>1178</td>
<td>77</td>
</tr>
</tbody>
</table>
Using eq. 23.1-23.5:

<table>
<thead>
<tr>
<th>One of the horizontal tubes</th>
</tr>
</thead>
<tbody>
<tr>
<td>da [mm]</td>
</tr>
<tr>
<td>di [mm]</td>
</tr>
<tr>
<td>Wall thickness [mm]</td>
</tr>
<tr>
<td>Min τ [MPa]</td>
</tr>
<tr>
<td>Min σ [MPa]</td>
</tr>
</tbody>
</table>

Aluminiumopmaat.nl has a tube with the following dimensions: 30x4 mm [23.3].

The bending of the buttock end of the tube can be calculated knowing all these forces and the dimensions of the tubes. This needs to be done to check if the sitting height will stay above 0.55 m when pressure is put on this tube.

Figure 23.5 – Vergeet-me-nietjes with a single force on the end of a beam

Using vergeet-me-nietjes (Fig. 20.5), it can be calculated that:

\[ w = \frac{1}{3} \frac{\text{bodyweight} \cdot l^3}{E \cdot I} \]

so the seat will stay above the 0.55 m line.

**Knee bar**

From the forces on the knee bar (Fig. 23.3) the moments on the knee bar can be determined.

\[ M_x = 0 \text{ Nm} \]
\[ M_y = F_{\text{bump}} \cdot 0.5 \cdot \text{tube length} = 0.5 \cdot 1178 \cdot 0.26 = 154 \text{ Nm} \]
\[ M_z = 0.5 \cdot F_{\text{body weight}} \cdot \gamma_{\text{length/feet - knee}} = 0.5 \cdot 785 \cdot 0.29 = 114 \text{ Nm} \]

**Summarized forces and moments:**

<table>
<thead>
<tr>
<th>Direction</th>
<th>Force [N]</th>
<th>Moment [Nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>( F_{\text{bump}} = 1178 )</td>
<td>0</td>
</tr>
<tr>
<td>Y</td>
<td>( F_{\text{full}} = 2355 )</td>
<td>154</td>
</tr>
<tr>
<td>Z</td>
<td>0</td>
<td>114</td>
</tr>
</tbody>
</table>

Knowing the all the forces and bending moments the desired tube diameter for the knee bar can be calculated. Using eq. 23.1-23.5:
A tube that can be found on aluminiumopmaat.nl has the following dimensions: 30x4 mm [23.3].

**Vertical tube**

Figure 23.3, shows all the forces on the sitting frame including the forces that act on the vertical tube. \( M_x = F_{bump} \times 0.5 \times \text{knee bar} = 589 \times 0.5 \times 0.26 = 77 \text{ Nm} \)

\[ M_y = F_{bump} \times (\text{knee distance} + \sin(10) \times \text{knee height}) = 1178 \times (0.29 + \sin(10) \times 0.436) = 430 \text{ Nm} \]

\[ M_z = F_{hand} \times 2 \times \text{distance center snowboard to handlebar} = 1013 \times 2 \times 0.33 = 669 \text{ Nm} \]

**Summarized:**

<table>
<thead>
<tr>
<th>Direction</th>
<th>Force [N]</th>
<th>Moment [Nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>( F_{fall} = 2355 )</td>
<td>77</td>
</tr>
<tr>
<td>Y</td>
<td>0</td>
<td>430</td>
</tr>
<tr>
<td>Z</td>
<td>( F_{bump} = 1178 )</td>
<td>669</td>
</tr>
</tbody>
</table>

Using eq. 23.1-23.5, and with making the tube 50 mm for the bearing:

A tube that can be found on aluminiumopmaat.nl has a tube with the following dimensions: 50x4 mm [23.3].

### In conclusion:

<table>
<thead>
<tr>
<th>Tube</th>
<th>Diameter</th>
<th>Wall thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sitting</td>
<td>25</td>
<td>3</td>
</tr>
<tr>
<td>Horizontal</td>
<td>30</td>
<td>4</td>
</tr>
<tr>
<td>Knee</td>
<td>30</td>
<td>4</td>
</tr>
<tr>
<td>Vertical</td>
<td>50</td>
<td>4</td>
</tr>
</tbody>
</table>

Since the tubes of the upper part, sitting, horizontal, and knee, are close to the same diameter and wall thickness they can be made out of the same tube diameter. This makes it cheaper to order the tubes and allows an esthetic bended tube design. VanderHoorn techniek [23.4] will be bending these tubes. This firm can bend this design with a tube with a diameter of 30 mm and a wall thickness of 5 mm.
Welding

The vertical tube will be welded onto the limiter plate, to make sure this weld will hold the weld needs to be calculated. The wall thickness of the vertical tube is 4 mm, from this wall thickness the weld thickness \( a \) can be determined:

\[
a \geq \sqrt{t_{\text{max}} \cdot 0.5 \text{ mm}} \Rightarrow a \geq \sqrt{4 - 0.5 \text{ mm}} \Rightarrow a \geq 1.5 \text{ mm} \tag{23.2}
\]

This makes it 3 mm thick.

The total shear can be determined with eq. 23.6:

\[
\sigma_{\text{w}} = \sqrt{\sigma_{\perp}^2 + \tau_{\parallel}^2 + \tau_{\perp}^2} \tag{23.2}
\]

In which \( \sigma_{\perp} = \frac{M_{\perp}}{I_w} \), \( \tau_{\parallel} = \tau_m = \frac{r_q}{\sum(a^2)} \) [eq. 23.7], and \( \tau_{\perp} = \frac{T \cdot e}{l} \) [eq. 23.8].

Since the weld will be around the edge of the tube \( l \) can be calculated, \( a \) is already known. Let’s assume the welding around the edge will be circular, it will be bigger in reality since it will go around the other tube a little and will thus be oval (Fig.23.4).

\[
l = \text{no of tubes} \cdot \pi \cdot d = 1 \cdot \pi \cdot 0.030 = 0.09 \text{ m}
\]

This makes \( A = a \cdot l = 3 \cdot 0.09 = 0.28 \text{ m} \). When assumed that the weld represents a thinwalled tube. This makes \( I_w = \frac{\pi}{4} (r_{\text{out}}^4 - r_{\text{in}}^4) \) and \( r_{\text{out}} = \text{outer diameter tube} + 2 \cdot \text{weld thickness} = 0.050 + 2 \cdot 0.0030 = 0.056 \text{ m} \) and \( r_{\text{in}} = 0.042 \text{ m} \). \( I_w = \frac{\pi}{4} (0.056^4 - 0.042^4) = 5.28 \cdot 10^{-6} \text{m}^4 \) and the polar moment of inertia will be: \( I_w = \frac{\pi}{2} (r_{\text{out}}^4 - r_{\text{in}}^4) = \frac{\pi}{2} (0.056^4 - 0.042^4) = 10.6 \cdot 10^{-6} \text{m}^4 \).

The maximum forces and moments for the weld have already been determined when the maximum forces in the vertical tube where verified.

**Summarized:**

<table>
<thead>
<tr>
<th>Direction</th>
<th>Force [N]</th>
<th>Moment [Nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>( F_{\text{fail}} = 2355 )</td>
<td>77</td>
</tr>
<tr>
<td>y</td>
<td>0</td>
<td>430</td>
</tr>
<tr>
<td>z</td>
<td>( F_{\text{bump}} = 1178 )</td>
<td>669</td>
</tr>
</tbody>
</table>

Using eq. 23.6-23.8 it can be seen that:

<table>
<thead>
<tr>
<th>Weld 1</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma_{\perp} ) [MPa]</td>
<td>5.24</td>
<td></td>
</tr>
<tr>
<td>( \tau_{\parallel} ) [MPa]</td>
<td>5.95</td>
<td></td>
</tr>
<tr>
<td>( \tau_{\perp} ) [MPa]</td>
<td>2.98</td>
<td></td>
</tr>
<tr>
<td>( \sigma_{\text{w}} ) [MPa]</td>
<td>8.47</td>
<td></td>
</tr>
</tbody>
</table>

Since this is lower than the ultimate tensile strength devided by the safetyfactor of 3 \( \frac{310}{3} = 103 \text{ MPa} \) the welds will be fine.
Sheet dimensions

In this design there is one sheet which is the limiter plate (Fig. 23.5). This plate will be made out of 6061 Aluminum alloy like the rest of the frame. To calculate the dimensions of a sheet the following equations should be used.

For the maximum moments

\[
\sigma_b = \frac{M_b}{W_x} \text{ [23.2]} \quad \text{in which} \quad W_x = \frac{1}{6}bh^3 = \frac{1}{6}b \cdot b \cdot h^2
\]

For the normal forces:

\[
\sigma_d = \frac{F_d}{A} \text{ [23.2]}\]

Limiter plate

The maximum forces and bending moments on this piece of sheet already have been calculated, since these are the maximum forces on the vertical tube. This sheet will be 0.2x0.66 m since this sheet will be attached to the top of the limiters which are 0.2 m in length and have a distance of 0.66 m between the outer edges of them.

Summarized:

<table>
<thead>
<tr>
<th>Direction</th>
<th>Force [N]</th>
<th>Moment [Nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>x</td>
<td>( F_{fall} = 2355 )</td>
<td>77</td>
</tr>
<tr>
<td>y</td>
<td>0</td>
<td>430</td>
</tr>
<tr>
<td>z</td>
<td>( F_{bump} = 1178 )</td>
<td>669</td>
</tr>
</tbody>
</table>

Knowing these forces and dimensions (0.66x0.2), using eq.23.9-23.11:

<table>
<thead>
<tr>
<th>Feet sheet</th>
<th>h [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>12</td>
</tr>
</tbody>
</table>
Solidworks verifications of sitting construction

Solidworks was used to verify the tubes of the complex sitting construction. The tube of the sitting construction was loaded with the two different maximum forces in y-direction and z-direction, one at a time; 1) $F_{\text{fall}}$ (y-direction) and 2) $F_{\text{bump}}$ (z-direction).

The material properties, fixtures, and mesh information was the same in each model.

### Material Properties

<table>
<thead>
<tr>
<th>Properties</th>
<th>Components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name: 6061-T6 (SS)</td>
<td>SolidBody 1(Sweep1)(Left side frame 80 kg 2013-10-11 1200)</td>
</tr>
<tr>
<td>Model type: Linear Elastic Isotropic</td>
<td></td>
</tr>
<tr>
<td>Default failure criterion: Max von Mises Stress</td>
<td></td>
</tr>
<tr>
<td>Yield strength: 275 N/mm$^2$</td>
<td></td>
</tr>
<tr>
<td>Tensile strength: 310 N/mm$^2$</td>
<td></td>
</tr>
</tbody>
</table>

### Fixtures

<table>
<thead>
<tr>
<th>Fixture name</th>
<th>Fixture Image</th>
<th>Fixture Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed-1</td>
<td></td>
<td>Entities: 1 face(s)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Type: Fixed Geometry</td>
</tr>
</tbody>
</table>

### Mesh Information

<table>
<thead>
<tr>
<th>Mesh type</th>
<th>Solid Mesh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mesher Used:</td>
<td>Standard mesh</td>
</tr>
<tr>
<td>Automatic Transition:</td>
<td>Off</td>
</tr>
<tr>
<td>Include Mesh Auto Loops:</td>
<td>Off</td>
</tr>
<tr>
<td>Jacobian points</td>
<td>4 Points</td>
</tr>
<tr>
<td>Element Size</td>
<td>9.20479 mm</td>
</tr>
<tr>
<td>Tolerance</td>
<td>0.46024 mm</td>
</tr>
<tr>
<td>Mesh Quality</td>
<td>High</td>
</tr>
</tbody>
</table>

### Mesh Information – Details

<table>
<thead>
<tr>
<th>Total Nodes</th>
<th>14043</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Elements</td>
<td>7034</td>
</tr>
<tr>
<td>Maximum Aspect Ratio</td>
<td>7.3017</td>
</tr>
<tr>
<td>% of elements with Aspect Ratio &lt; 3</td>
<td>94.6</td>
</tr>
<tr>
<td>% of elements with Aspect Ratio &gt; 10</td>
<td>0</td>
</tr>
<tr>
<td>% of distorted elements(Jacobian)</td>
<td>0</td>
</tr>
</tbody>
</table>

Each load resulted in different Von Mises stresses in the construction.
**Frall**

<table>
<thead>
<tr>
<th>Load name</th>
<th>Load Image</th>
<th>Load Details</th>
</tr>
</thead>
</table>
| Force-1   | ![Load Image](image1.png) | Entities: 1 face(s), 1 plane(s)  
Reference: Plane4  
Type: Apply force  
Values: ---, ---, -2355 N |

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stress</td>
<td>VON: von Mises Stress</td>
<td>1.30354e-011 N/mm² (MPa)</td>
<td>259.502 N/mm² (MPa)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Node: 2355</td>
<td>Node: 261</td>
</tr>
</tbody>
</table>

The Von Mises stresses in the construction never go beyond the yield strength, which means that the construction will not plastically deform during use if the forces represent real life.
**F_bump**

<table>
<thead>
<tr>
<th>Load name</th>
<th>Load Image</th>
<th>Load Details</th>
</tr>
</thead>
</table>
| Force-1   | ![Load Image](image) | Entities: 1 face(s), 1 plane(s)  
Reference: Top Plane  
Type: Apply force  
Values: ---, ---, -1178 N |

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
</table>
| Stress | VON: von Mises Stress | 2.59646e-011 N/mm^2 (MPa)  
Node: 10091  
189.804 N/mm^2 (MPa)  
Node: 12445 |

The Von Mises stresses in the construction never go beyond the yield strength, which means that the construction will not plastically deform during use if the forces represent real life.

**References:**


Appendix 24

Propulsion check
Propulsion

The design decision that has to be taken here is to take out either one or two handlebars to propel the sit-snowboarder. Taking out one handlebar results in only being able to propel with one handlebar whilst taking out two handlebars allows the sit-snowboarder to propel him-/her-self with two handlebars. However taking out two handlebars might leave the sit-snowboarder unbalanced due to the fact that the direct feedback with the snowboard is lost (the user is assumed to have no feeling in his/her legs).

Two test persons tried to propel themselves with one and with two ski-poles in MINI during a test in indoor snowsport facility Snowworld Zoetermeer. The outcome of this test was that propelling with one ski-pole is not only hard since it requires quite some force to actually move but it also showed that the user will start going round in circles. This circle pattern can be broken by using the ski-pole alternating on each side, however this results in the pattern shown in Figure 24.1 and is not efficient. It seems that it would be better to take both the handlebars out. This propulsion method was only tested by 2 people, this means that the test results are just an indication and nothing final can be concluded from this test, further testing should verify this assumption.

![Figure 24.1 - Propulsion track with alternating one ski-pole, the red dot is the ski-pole track](image)

A sit-skier uses two outriggers to propelling him-/her-self in the snow. These outriggers can either be used to glide on and maintain balance or they can be used similar to ski-poles for propulsion (Fig. 24.2).

![Figure 24.2 - Outriggers are part of sit-skiers equipment and can be used in two configurations; A) outriggers used to glide on, B) outriggers used to propel](image)
Appendix 25
Handlebar Design
In this Appendix information can be found on the design of the handlebar including the click mechanism. Starting off with the design choices and followed by calculations needed to determine the dimensions of the handlebar.

**Concepts of sit-snowboards enabling chairlift usage**

It is decided to let the tail side handlebar make way for the chairlift (App. 19). Possible ways to do so are; placement and shape of the handlebars, folding the handlebar, making the handlebar telescopic, removing the handlebar, rotating the handlebar, or translating the handlebar (Table 25.1).

<table>
<thead>
<tr>
<th>Placement and shape</th>
<th><img src="image1" alt="Diagram" /> <img src="image2" alt="Diagram" /></th>
</tr>
</thead>
<tbody>
<tr>
<td>Folding</td>
<td><img src="image3" alt="Diagram" /> <img src="image4" alt="Diagram" /></td>
</tr>
<tr>
<td>Telescopic</td>
<td><img src="image5" alt="Diagram" /></td>
</tr>
<tr>
<td>Removing</td>
<td><img src="image6" alt="Diagram" /></td>
</tr>
<tr>
<td>Rotating</td>
<td><img src="image7" alt="Diagram" /></td>
</tr>
<tr>
<td>Translating</td>
<td><img src="image8" alt="Diagram" /></td>
</tr>
</tbody>
</table>

Table 25.1 – Different design options for the handlebars

It was chosen to detach the handlebars since detaching the handlebars allows for the sit-snowboarder to use the handlebars as a mechanism for propulsion, balance, and stabilization during loading and unloading of the chairlift which all benefits the user's independence. Another reason to choose the detachable handlebar is that most of the other options had moving parts and a large number of parts which is expected to break down more easily.
Concepts Handlebar locking mechanism

Concept 1: Crutch

In the Crutch concept (Fig. 24.1) a cable runs from a bicycle brake handle to this mechanism, $F_{\text{Cable}}$ is the force applied to the mechanism with the break handle. A spring (red) pushes the pins (blue) outward to lock the mechanism, the cable (green) applies a retracting force to the pins, $F_{\text{pin}}$. When the pins are retracted the mechanism is unlocked.

Ease of use; Number of proceedings

Lock: slide down (1)

Unlock: Exert force on pins, slide up, let pins go (3)

Total: 4

Ease of use; Difficulty of proceedings

The upper and lower part need to slide into one another, this can be guided by the construction. The sit-snowboarder can see what he/she is doing which makes it easier to operate this mechanism. The lower and upper part can also be designed in such a way that only one configuration is logical and easy to operate.

Grade of difficulty: -1

Standardization

The parts are relatively standard and the click mechanism can be taken out of a crutch, a bicycle brake can be used to operate the mechanism.

Standardization: +2

Robustness; Snow-proof

Snow can get stuck in between the top and bottom have of this construction, however by leaving a ledge of some sort the snow can get past the lower part whilst the top part gets restricted for further movement by the ledge. Snow in the smaller parts of this construction would be a bigger issue, but this part of the construction can be shielded from the snow completely.

Robustness: -1

Force calculations

Based on DINED values of a p5 population [24.1], the user can generate a gripping force of 230 N at the most. These type of pins can also be found in crutches, where the user will pinch the pins inside the crutch. Knowing that the maximum tip pinch force of a female is maximally 47.87 N [24.2], and assuming that the maximum pinching force of the crutch is 1/2 of the maximum force, the operating force of the crutch would be 24 N. Since a break handle is used as a lever it is assumed that this mechanisms can easily be operated by the sit-snowboarder. The exact forces depend on the dimensions of the diamond shaped wire construction (Fig. 24.1).
Concept 2: Clamp

The Clamp concept (Fig. 24.2) consists of a rubber piece which will be used as a spring, and can be contracted by the use of a wire which determines the amount of contraction. When the rubber is contracted it will deliver a force outward to the 'loose' parts that clamp the system into place. At the top of these parts there will be a spring hinge which will keep the parts/clamps contracted inward. This mechanism could also be made compliant, this would however make the design of the mechanism harder.

The weakness in this design is that there are a lot of parts which have to work together in their separate space. This combination of parts can easily get stuck due to snow and ice. This mechanism is also prone to accidental pushing of the rubber, which would unlock the entire mechanism.

**Ease of use; Number of proceedings**

**Lock:** slide down (1)

**Unlock:** Exert force on rubber, slide up, release rubber (3)

**Total:** 4

**Ease of use; Difficulty of proceedings**

The sit-snowboarder has to find the exact right spot to slide the upper part down onto, this might cause some difficulties since it is hard to see and feel this lower part.

**Grade of difficulty:** -2

**Standardization**

Every single part can be created quite easily but most of them are not standard parts. If this mechanisms would be produced in a compliant version that would be an even more complicated part to make.

**Standardization:** -1 (non-compliant) / -2 (compliant)

**Robustness; snow-proof**

In the non-compliant version snow can easily get stuck between the hinges, which would make the entire mechanism useless. The compliant version might not respond the same during the use at different temperatures and can also fill up with snow quite easily.

**Robustness:** -2 (non-compliant) / -1 (compliant)

**Force calculations**

The moments put on this concept have to be counteracted by the springs in this system. These forces are quite high, \( F_{hand} \cdot h_{max-handlebar} = 1013 \cdot 0.826 = 836.74 \text{ Nm} \) (App.20), and this means that the spring needs to be really strong to make sure that it is not going to break out during use.
**Concept 3: Bayonet with spring**

![The Bayonet with spring concept for the locking mechanism of the handlebars.](image)

The Bayonet with spring concept is displayed in Figure 24.3. The bayonet is supposed to make sure that the user cannot unlock the system with any sudden movement. The spring is making sure that the sit-snowboarder needs to combine a pressing and turning motion to unlock the system. There is a chance that the sit-snowboarder might still combine these two motions accidentally which would unlock the mechanism unexpectedly.

**Ease of use; Number of proceedings**

**Lock:** slide down, press, down, twist (2)

**Unlock:** press down, twist, pull up (3)

**Total:** 6

**Ease of use; Difficulty of proceedings**

This mechanism is relatively easy to use, the sit-snowboarder only has to keep the position of then handlebar right, push, twist, and turn. Even though this is fairly simple in comparison with other ideas, the numbers of proceedings are a lot and the combination of pressing and turning might cause some confusion.

**Degree of difficulty:** -1

**Standardization**

Most of the parts are fairly easy to get of the shelve. A problem might be the size of some of the parts.

**Standardization:** +1

**Robustness; Snow-proof**

Everything in this design is designed in such a way that snow can get out of the system, however the spring can still be exposed to the snow and ice which might jam the system.

**Robustness:** -1

**Force calculations**

The forces to keep the joint in place have to be equal or greater than the maximum forces expected from the user. These forces will be equal to $F_{\text{hand}} = 1013 \, N$, this means that for the user to unlock this system he/she needs to put more force than 1013 N on the system and since this is the maximum force a user can put on the system and his/her body weight will be 785 N or less a problem is foreseen with this.
Concept 4: Pin

In the Pin concept (Fig. 24.4) a shaft will be slid into the front end of the tubing and a pin will be slid down to keep this shaft in place. Everything is closed by shape which means that the shaft cannot twist or turn. The only exit for the shaft is blocked by the pin. A disadvantage of this mechanism is the pin that will be loose during the chairlift ride.

Ease of use; Number of proceedings
Lock: slide in from the front, shove pin down (2)
Unlock: slide pin up and slide shaft forward (2)
Total: 4

Ease of use; Difficulty of proceedings
Sliding the shaft in and out of its compartment needs to be done perfectly straight or it will get stuck. Another thing that is hard to do is that the pin needs to be exactly in place to be able to slide it down which is very hard to see for the user. It is however an option to make both of these things tapered in design.

Degree of difficulty: -2

Standardization
All the parts can be easily made and are easy to implement.

Standardization: +2

Robustness; Snow-proof
Both the pin compartment and the shaft compartment can get filled with snow. When this happens the snow has nowhere to go and the mechanism gets jammed.

Robustness: -2

Force calculations
It is expected that the shaft fails first, due to the thin piece that connects the upper part to the lower part. Maximum forces in \( x \)-, \( y \)-, and \( z \)-direction are \( F_{\text{hand}} = 1013 \ N \) (App. 20), the maximum moments are \( F_{\text{hand}} \times h_{\text{max-handlebar}} = 836.74 \ Nm \) for the \( x \)-, and \( y \)-direction and \( F_{\text{hand}} \times \text{max distance to center} = 1013 \times 0.26 = 263.38 \ Nm \) in the \( z \)-direction.
To make sure that the shaft will withstand the forces, the size needs to be equal to (taken that it is made out of 6061 alloy Aluminum, \( \sigma_b = 310 \ MPa \)):

The maximum bending moment: 

\[
\bar{\sigma}_b = \frac{\sigma_b}{S_{\text{dmin}}} \quad [24.3]
\]

With the safety factor \( S_{\text{dmin}} = 3\ldots 4 \) for dynamic loads [24.3]

\[
\bar{\sigma}_b = \frac{310 \ MPa}{4} = 77.5 \ MPa .
\]

Due to the pressing forces:

\[
\sigma_d = \frac{F_d}{A} \Rightarrow 77.5 \times 10^6 \ MPa = \frac{1013 \ N}{A} \Rightarrow A = 1.31 \times 10^{-5} \ m^2
\]

So the surface area \( (A) \) of this needs to be \( 1.31 \times 10^{-5} \ m^2 \) or more to withstand the forces. Let’s say that the side will be 40 mm.

Due to the moments:

\[
M_{x-\text{max}} = 836.74 \ N \times m
\]

\[
\sigma_b = \frac{M_b}{W_c} \quad \text{with} \quad W_c = \frac{I_x}{e^2} \quad (I_x \text{ is the inertia, and } e \text{ is the distance to the center line}) \quad [24.3]
\]
Filling out these equations:

\[ W_x = \frac{1}{6} \frac{b_x h^3}{h^2} = \frac{1}{6} b_x h^2 \]  

\[ \sigma_b = \frac{M_h}{W_x} = \frac{M_{x_{\text{max}}}}{\frac{1}{6} b_x h^2} \]  

\[ \Rightarrow 77.5 \times 10^6 \text{ MPa} = \frac{836.74 \text{ N} \cdot \text{m}}{\frac{1}{6} \times 0.04 \text{ m} \times h^2} \]  

This would mean that the middle piece needs to be at least 40 mm wide in order to hold all these forces. This is big and heavy, making it an unpractical solution.

**Concept 5: Push and twist**

In the Push and twist concept (Fig. 24.5) the tubes need to be placed on top of one another and then a pin inside will be twisted to lock the catch in the mechanism.

![Figure 24.5 - The Push and twist concept for the locking mechanism of the handlebars.](image)

**Ease of use; Number of proceedings**

**Lock:** slide down, twist catch (2)

**Unlock:** twist catch, slide up (2)

**Total:** 4

**Ease of use; Difficulty of proceedings**

It can get really difficult to get the catch in the exact right position since you cannot see it once it is in the system.

**Degree of difficulty:** -2

**Standardization**

Both the catch and the squared tubes are easy to make and get which makes this a very easy design.

**Standardization:** +2

**Robustness; Snow-proof**

With the snow and the cold the catch could get stuck due to ice. Snow could jam the system when it gets caught between the lower and upper part of this system.

**Robustness:** -2

**Force calculations**

The use of this catch does not have to be hard, as long as the catch can glide smoothly the rod will not twist.

**CONCLUSION:**

From this chart it can be seen that the concept Crutch will be a good solution for this design problem. Even though the concept Push and Twist also seems like a viable solution the inconvenience to the user seems to be too great.
Calculations Design Handlebar

The handle bars will have to sustain forces produced by the riders hand and forces produced by a fall. The forces produced by a hand can maximally be \( F_{\text{hand}} = 1013 \, N \) in either direction \((x, y, z)\) and on any point on the handlebar grip surface (green surface Fig. 25.7). Both of the handlebars will have to endure the same forces and bending moments, and will be designed in the same manner. The handlebar will consist of an upper part and a lower part which will glide into one another (Fig. 25.7C). The upper part will have an insert which has two pins which will lock the system.

![Figure 25.7 – Handlebar; A) Dimensions handlebar, B) Forces on the handlebar caused by hand forces of the sit-snowboarder, C) definitions of the handlebar parts](image)

**Upper part handlebar**

The grip of the handlebar will stay the same. The 3 welded tubes will be lengthened since the lower part needs to be lower for it not to hit the chairlift chair and the handlebar needs to be higher to compensate for the raise in sitting height of the sit-snowboarder. The raise in height of the 3 welded tubes will raise the moments in this part, by maximally \( \text{raise in height} \times \frac{F_{\text{fall}}}{2} = 0.056 \times \frac{2355}{2} = 65.94 \, Nm \). Right above this region there is a moment of \( 0.58 \times \frac{2355}{2} = 682.95 \, Nm \) which will be divided over 2 tubes, so easily said 342 Nm per tube. In the lowest part of the three tubes coming together there is a moment of \( 0.65 \times \frac{2355}{2} = 765.38 \, Nm \) raised with the 65.94 Nm we calculated earlier, this would come up to 831.32 Nm divided over three tubes means 278 Nm per tube. Which is much lower than the 342 Nm calculated before so the tubes will hold the raise in height.

**Connection lower and upper part of handlebar**

The three tubes of the upper part of the handlebar will be welded into the inner tube, which in turn will be clicked into the outer tube. The highest force on the handlebar will be \( F_{\text{fall}} \) (Fig. 25.9). Since it is known that \( \frac{F_{\text{fall}}}{2} = 1178 \, N \), \( F1 \) and \( F2 \) can be calculated since \( \Sigma F = 0 \) and \( \Sigma M = 0 \). With \( a = 0.736 \, m \) and \( b = 0.2 \, m \) this results in \( M_{\text{max}} = 868 \, N \). In order for the insert to fit into the inner tube the inner diameter of the inner tube needs to be at least 54 mm. Using the excel sheet (App. 23) it can be calculated that this tube needs to be 63x4 mm, and the outer tube needs to be at least 70x3 mm. Looking at
tubes available and in order to fit a bearing material in between the two tubes it was chosen to use an inner tube of 65x5 mm and an outer tube of 80x3 mm [25.8].

![Figure 25.9 - Forces and moments distribution in the handlebar tubes](image1)

![Figure 25.10 - Locking mechanism of the handlebars](image2)

**Click mechanism**

The insert will contain a click mechanism (Fig. 25.10). The only forces on the click mechanism will be the forces and moments on the pins of the click mechanism. These forces determine the dimensions of the pins. The length of the pins can be calculated knowing the dimensions of the inner and outer tube. Adding a margin of 2.5 mm so the user can see the end of the pin sticking out, the length of the pins will need to be 12.5 + 2.5 = 15 mm.

In order to keep the dimensions small it was decided to make the pins out of stainless steel (Table 25.2). [25.3][25.4][25.5][25.6][25.7]

**Stainless steel**

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density:</td>
<td>$\rho = 8 \text{ g/cm}^3$</td>
</tr>
<tr>
<td>Young's Modulus:</td>
<td>$E = 68.9 \text{ GPa}$</td>
</tr>
<tr>
<td>Ultimate Tensile Strength:</td>
<td>$\sigma_t = 505 \text{ MPa}$</td>
</tr>
<tr>
<td>Tensile Yield (plastic deformation) Strength:</td>
<td>$\sigma_y = 215 \text{ MPa}$</td>
</tr>
<tr>
<td>Shear Modulus:</td>
<td>$G = 86 \text{ GPa}$</td>
</tr>
<tr>
<td>Shear Strength:</td>
<td>$\tau = 225 \text{ MPa}$</td>
</tr>
<tr>
<td>Poisson's Ratio:</td>
<td>$\nu = 0.29$</td>
</tr>
</tbody>
</table>

Table 25.2 - Material properties for stainless steel
Figure 25.7B displays the forces produced by arm power of the sit-snowboarder, $F_{\text{hand}} = 1013 \, N$. These red forces represent the force direction that is most likely to happen, the orange represents the most common force and the actual desired force during riding. The orange force therefore can be either in this or the opposite direction and will both happen around the same number of times, since the sit-snowboarder will make heel side turns and toe side turns. Other forces on the handlebar are caused by falling, $F_{\text{fall}}$. The click mechanism will be placed in the lower part of the handlebar. The maximum moments can be found just above the snowboard. The maximum height of the handlebar is 0.936 m.

\[
M_x = F_{\text{hand}} \times \text{max height} = 1013 \times 0.936 = 949 \, Nm \\
M_y = F_{\text{hand}} \times \text{max height} = 1013 \times 0.936 = 949 \, Nm \\
M_z = F_{\text{fall}} \times \text{distance handlebar center to outer edge} = 2355 \times 0.2 = 471 \, Nm
\]

**Summarized:**

<table>
<thead>
<tr>
<th>Direction</th>
<th>Force [N]</th>
<th>Moment [Nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x$</td>
<td>$F_{\text{hand}} = 1013$</td>
<td>949</td>
</tr>
<tr>
<td>$y$</td>
<td>$F_{\text{fall}} = 2355$</td>
<td>949</td>
</tr>
<tr>
<td>$z$</td>
<td>$F_{\text{hand}} = 1013$</td>
<td>471</td>
</tr>
</tbody>
</table>

This torsional moment (Moment z-direction) will be put on two pins and the highest force will take place at the outer diameter of the inner tube, which is on 0.065/2 m from the center. This results in a force of: $\frac{471/2}{0.065/2} = 7247 \, N$. For stainless steel $\tau_{\text{max}} = 225$ [25.3]. For a solid pin the dimensions can be calculated with the following equations.

For the maximum shear stress: $\tau_{\text{max}} = \frac{4}{3} \times \frac{K_A \times F}{2 \times A} \leq \tau_0 = 225 \, [25.3]$

$K_A$ is the service factor, $F$ is the maximum shear force, $A$ is the surface area of the pin

\[
\frac{4}{3} \times \frac{2 \times 7247}{2 \times 0.25 \times \pi \times d^2} \leq \frac{225}{3} \, \text{MPa} \Rightarrow d = 0.013 \, \text{m}
\]

To make this a more standard size it was chosen to make the pins 15 mm.

When using the lock mechanism there are two situations; one in which the pins are fully withdrawn and situation 2 in which they are fully extended.

For $a_2$, the pins are fully extended against the inner wall of the inner tube so we know $a_2 = 65 - 2 \times 5 = 55 \, mm$. In situation one the pins need to be inside the inner tube which has a diameter of 65 mm and a wall thickness of 5, since the pins are 15 mm and the outer tube has a wall thickness of 5 mm each pin will need to come in 7.5 mm making $a_1 = 55 - 2 \times (7.5) = 40 \, mm$. 

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In order to calculate the dimensions of both \( b \) and \( c \) (Fig. 25.12) the forces needed to withdraw the pins and the gripping force of a human hand need to be known. The pins that will be used in this mechanism can also be found in crutches. Knowing that the maximum tip pinch force of a female is maximally 47.87 N [25.2]. Assuming that the maximum pinching force of the crutch is 1/2 of the maximum force, than the operating force of the crutch would be 24 N.

To calculate the operating of the brake handle of the bicycle brake the gripping force needs to be known. The maximum gripping strength for a P5 young adult 20-30 years is 230 N according to DINED [25.9]. To comfortably operate this system assume half of this maximum force, 115 N.

\( F_{\text{pull}} \) is probably going to be bigger than 115 N since the brake handle allows for a wedge action minus the friction in the cable. Since the cable is going to have some friction and elongation assume a 5 N loss of force. This means that \( F_{\text{pull}} = \text{wedge} \times 110 - \text{friction} = \left( \frac{10}{1} \right) \times 110 - 5 = 1095 \text{ N}. \) For the ease of calculation assume that point B and C stay on the same height since the pins need to be pulled out of the outer tube right there. Since the cable length stays the same point D will need to go up, this point D is assumed to go straight up.

Summarizing the two positions:

<table>
<thead>
<tr>
<th>Position</th>
<th>Length ([\text{mm}])</th>
<th>( b ) ([\text{mm}])</th>
<th>Length ( c ) ([\text{mm}])</th>
<th>Alpha ([\text{deg}])</th>
<th>Beta ([\text{deg}])</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>40</td>
<td>( b_1 )</td>
<td>( c )</td>
<td>( \tan^{-1}\left(\frac{b_1}{0.5 \times a_1}\right) )</td>
<td>( \tan^{-1}\left(\frac{c}{0.5 \times a_1}\right) )</td>
</tr>
<tr>
<td>2</td>
<td>55</td>
<td>( b_2 )</td>
<td>( c )</td>
<td>( \tan^{-1}\left(\frac{b_2}{0.5 \times a_2}\right) )</td>
<td>( \tan^{-1}\left(\frac{c}{0.5 \times a_2}\right) )</td>
</tr>
</tbody>
</table>

The forces in the system can be expressed as follows:

\[ F_{\text{cable}} = 0.5 \times F_{\text{pull}} = 548 \text{ N} \]

\[ F_c = F_{\text{cable}} \times \cos(\alpha) \] the bigger \( \alpha \) the lower \( F_c \) to withdraw the pins \( F_c \geq 24 \text{ N} \) at all times so even at the biggest \( \alpha \) which is in position 1, the withdrawn position. Since \( F_{\text{cable}} = 548 \text{ N} \) it can be calculated that;

\[ F_c = F_{\text{cable}} \times \cos(\alpha_1) + F_{\text{cable}} \times \cos(\beta_1) \]

Assumed that \( \alpha_1 = \beta_1 \), then;

\[ \alpha_1 = \cos^{-1}\left(\frac{F_c}{2 \times F_{\text{cable}}}\right) = 89^\circ \]

Since it is known that \( \alpha_1 = \tan^{-1}\left(\frac{b_1}{0.5 \times a_1}\right) \) it can be calculated that: \( b_1 = \tan(\alpha_1) \times 0.5 \times a_1 \Rightarrow b_1 = \tan(89) \times 0.5 \times 40 = 1146 \text{ mm} \). Which means that the height of \( b \) can maximally be 1.1 m. This can easily be realized.
**Lower part handlebar**

In order for the lower part not to hit the chairlift whilst it goes over the board the bottom part needs to stay below the 21 cm limit. In order to do so the lower part of the handlebar part can just be trimmed down (Fig. 25.14).

![Diagram of old and new handlebar versions](image)

**Figure 25.14** – The old and new versions of the lower part of the handlebar

**References:**


Appendix 26
Prototype Design Choices
In this Appendix the design choices made during the prototype design process are described and analyzed.

**Important rejected design choices**

<table>
<thead>
<tr>
<th>Choice number</th>
<th>Choice</th>
<th>Reasoning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bearing seat construction</td>
<td>• Proven product&lt;br&gt;• Easy to get&lt;br&gt;• Small&lt;br&gt;• Light weight</td>
</tr>
</tbody>
</table>

The bearing chosen to switch from the rider to the chairlift position was a Igus PRT Ronddraaitafel, type PRT-01-60 bearing from Elcee. It has been used for similar products in snowy, cold, and changing weather conditions. It is easy to get, since it just needs to be ordered. It is small in size, d160 mm x h33 mm, and light in weight, 1.1 kg.

**Reason for rejection:** Cost; this bearing would cost 173,70 euro’s.

<table>
<thead>
<tr>
<th>Choice number</th>
<th>Choice</th>
<th>Reasoning</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Bearing handlebars</td>
<td>• Proven concept</td>
</tr>
</tbody>
</table>

The upper and lower part of the handlebars have to slide in and out of each other. To do this it was chosen to use POM. This is a proven concept in both warm and cold temperatures and would be suitable for this application.

**Reason for rejection:** Cost; this amount of POM would cost 97,- euro’s per handlebar.

**Design choices during prototype building**

<table>
<thead>
<tr>
<th>Choice number</th>
<th>Choice</th>
<th>Reasoning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Two different locking mechanism in handlebars</td>
<td>• Testing options&lt;br&gt;• Time constraint</td>
</tr>
</tbody>
</table>

The locking mechanism with the break handle was not constructed well in the beginning and proposed a lot of problems, it was then decided to try another mechanism in case the mechanism with the break handle would not work. It was then that they both worked.

<table>
<thead>
<tr>
<th>Choice number</th>
<th>Choice</th>
<th>Reasoning</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>Two different locking mechanism seat construction</td>
<td>• Testing options&lt;br&gt;• Space limitations</td>
</tr>
</tbody>
</table>

It was decided to make a locking mechanism with one pin but there was limited space, that is when the design with two pins came into play. This option however proposed a lot of problems with alignment. When testing this option it was noticed that there was space for the one pin after all, this is when it was decided to try this option too. The one pin worked a lot better and was kept in the design.

<table>
<thead>
<tr>
<th>Choice number</th>
<th>Choice</th>
<th>Reasoning</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>PVC bearings in handlebars</td>
<td>• Cost efficient&lt;br&gt;• Time efficient</td>
</tr>
</tbody>
</table>

In the important rejected design choices it can be seen that the POM option was too expensive a cheap alternative was sought and PVC replaced the POM. To reduce the cost even further the bearing was made out of two smaller pieces and not place over the entire length of the overlap between upper and lower part of the handlebar.

<table>
<thead>
<tr>
<th>Choice number</th>
<th>Choice</th>
<th>Reasoning</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>PVC bearing attached to the upper part of the handlebar</td>
<td>• Lower part would not work</td>
</tr>
</tbody>
</table>
The PVC bearing was placed on the outside of the upper part of the handlebar since the shrink ratio, showed that placing the PVC bearing on the inside of the lower part would result in the PVC shrinking more than the aluminum tubing which would make the PVC get stuck between the two pieces of tube or get attached to the upper part after all.

5 4 mm thick aluminum under handlebars, and entire construction
   • Cost efficient
   • Time efficient

The 4 mm thick aluminum under the handlebars, and entire construction was chosen since it was available at the PMB (workshop at the TU Delft), this made it not only a cost efficient but also time efficient solution.

6 Bearing and housing in seat construction
   • Cost efficient

Since the bearing from Elcee was too expensive, see important rejected design decisions, it was chosen to make a bearing and housing at PMB. With the materials and equipment at hand this bearing was created. With more time and money a lighter and smaller design could be made.

7 Limiter plate
   • Light weight

The limiter plate that was designed was a mere test of principle. As designed this limiter plate would be created out of a 20 mm thick aluminum slap and weight 7.13 kg. It was decided to design a new limiter plate based on experience, a 12 mm thick piece of wood was coated with glass-fiber and epoxy. It is relatively light weight.

8 Feet pads and attachment
   • Cost efficient
   • Time efficient

The feet pads used on MINI were not sufficient since they had no bottom, on SnowGo the feet would float so they needed something to rest on. It was decided to make a quick solution with the materials available which resulted in these feet pads. The attachment was chosen to make the distance between feet and knee pads flexible which makes it adjustable for different users. All was created with materials and machines available at PMB to make them quick and cheap.
Appendix 27
Design drawings - SnowGo
On the disk at the back of this report all the design drawings of SnowGo can be found.
(1) Seat construction (drawing 1.1)
(2) Handlebars (drawing 1.2.)
Appendix 28
Design Drawings – Test set-up’s
On the disk at the back of this report all the design drawings of the test set-up's can be found.
(1) connection tube (drawing 1.1)
(2) side tube (drawing 1.2)
(3) front tube (drawing 1.3)
(4) back tube (drawing 1.3)
(5) attachment plate (drawing 1.5)
(6) base plate (1000x1700x12 mm plywood)
(7) board protection plate (drawing 1.7)
(8) front plate (drawing 1.8)
(1) plate 1 (drawing 1.1)
(2) attachment plate 2 (drawing 1.2)
(3) attachment plate 3 (drawing 1.3)

Number of times needed per set up: 1x

Attached with inserts an bolds.
Appendix 29

Method of Validation - Lab Test (Handlebar)
In this Appendix the method of validation of the handlebar can be found.

Validation experiment

1. Introduction

Earlier prototypes showed that the handlebars are used to initiate a turn. In order to do so the handlebar needs to be able to twist the board. In order to verify the working of SnowGo the ability to twist the snowboard with SnowGo’s handlebars is compared to the amount of twisting created with MINI’s handlebar.

The test described in this document is used to verify the following hypothesis;

Hypothesis:
1.1. In order to tilt the board 10 degrees, less weight has to be used using SnowGo than using MINI.

2. Materials

Materials needed for these test are listed below;

2.1. SnowGo incl. snowboard - new prototype created by Michelle Hoogwout, incl. Atomic Piq, learn to ride snowboard, with a length of 1.55 m
2.2. MINI incl. snowboard - prototype created by Prodaptive, incl. Atomic Piq, learn to ride snowboard, with a length of 1.55 m
2.3. Weight – at least 100 kg to apply force (measurement weight, counter weight)
2.4. Snowboard Standard - to restrain snowboard (App. 28)
2.5. Inclinometer - to measure tilt angle
2.6. Rope – to attach weight and counter weight to the prototype (make sure the same rope is used during the entire procedure)
2.7. Pulleys – to attach counter weight (Fig. 29.2)

3. Setup procedure

The setup should comply with the following guidelines

3.1. Place the snowboard incl. prototype (MINI or SnowGo) inside the standard in a vertical position (Fig. 29.1). This construction will restrain the board at the middle.
3.2. Record the following information on the data form.

3.2.1. Organization, address, phone, and test administrators
3.2.2. Date, time, location
3.2.3. Take photographs of the object, the test environment, and the test set up

4. Collect Deflection Measurements

The deflection measurements of the handlebars will be performed in two positions; 1) the snowboard is placed in the standard horizontally with the heel side pointing towards the floor, and 2) the snowboard is placed in the standard horizontally with the toe side pointing towards the floor. This procedure concludes one test, this test needs to be performed twice; once with prototype MINI and once with SnowGo.
4.1. **Position 1** (heel side to floor)

4.1.1. **DM\textsubscript{1}** will be the relaxed position of the snowboard in the construction

4.1.1.1. To acquire a neutral position, counter weight has to be attached to the prototype to compensate for the weight of the prototype. This counter weight is attached to the prototype by means of ropes and pulleys (Fig. 29.2). Position 1 requires the ropes to be attached to point A on the handlebar and the knee bar of the sitting construction. Attach the counter weight on the rope in steps of 1 kg. After each kg added to the rope measure the tilt angle of the snowboard-standard, and the snowboard at the specified places (Fig. 29.2B, spot 1-4). Stop adding counter weight when the tilt angle of the standard (spot 4) is within one degree of the tilt angle of the measurement spots on the snowboard (spot 1-3).

4.1.1.2. Measure the tilt angle of the base plate, the snowboard-standard, the handlebar, and the snowboard measurement spots (Fig. 29.2) with an inclinometer and write the measurement data down on a data form.

4.1.2. **DM\textsubscript{2}** will be the weighted position of the snowboard in the standard

4.1.2.1. Attach 1 kg to position B by means of rope, and measure the tilt angle of the tip of the snowboard (Fig. 29.2B, spot 3). Continue this procedure and stop when the tilt-angle of the tip of the snowboard reads a 10 degrees difference from the unloaded tilt angle.

4.1.2.2. Measure the tilt angle of the base plate, the snowboard-standard, the handlebar, and the snowboard measurement spots (Fig. 29.2) with an inclinometer and write the measurement data down on a data form.

4.1.2.3. Write down the amount of weight put on the handlebar.

4.2. **Position 2** (toe side to floor)

4.2.1. **DM\textsubscript{1}** will be the relaxed position of the snowboard in the construction

4.2.1.1. To acquire a neutral position, counter weight has to be attached to the prototype to compensate for the weight of the prototype. This counter weight is attached to the prototype by means of ropes and pulleys (Fig. 29.2). Position 2 requires the ropes to be attached to point B on the handlebar and the sitting tube of the sitting construction. Attach the counter weight on the rope in steps of 1 kg. After each kg added to the rope measure the tilt angle of the snowboard-standard, and the snowboard at the specified places (Fig. 29.2B, spot 1-4). Stop adding counter weight when the tilt angle of the standard (spot 4) is within one degree of the tilt angle of the measurement spots on the snowboard (spot 1-3).

4.2.1.2. Measure the tilt angle of the base plate, the snowboard-standard, the handlebar, and the snowboard measurement spots (Fig. 29.2) with an inclinometer and write the measurement data down on a data form.

4.2.2. **DM\textsubscript{2}** will be the weighted position of the snowboard in the standard

4.2.2.1. Attach 1 kg to position A by means of rope, and measure the tilt angle of the tip of the snowboard (Fig. 29.2B, spot 3). Continue this procedure and stop when the tilt-angle of the tip of the snowboard reads a 10 degrees difference from the unloaded tilt angle.

4.2.2.2. Measure the tilt angle of the base plate, the snowboard-standard, the handlebar, and the snowboard measurement spots (Fig. 29.2) with
an inclinometer and write the measurement data down on a data form.

4.2.2.3. Write down the amount of weight put on the handlebar.

4.3. **Calculate** the difference between MINI and SnowGo by subtracting the weight used on SnowGo’s handlebars from the weight used on MINI’s handlebars.

The calculation of difference is determined by:

\[ \text{Difference} = \text{Weight}_{\text{SnowGo}} - \text{Weight}_{\text{MINI}} \quad \text{[Eq. 29.1]} \]

4.3.1. If the calculated difference result is negative, the weight put on SnowGo was less than the weight put on MINI.

5. **Terminology - definitions**

5.1. **SnowGo** – New prototype, created by Michelle Hoogwout (Fig. 29.3, App. 27)
5.2. **MINI** – Former prototype created by Prodaptive (Fig. 29.4)
5.3. **Handlebar** - tube constructions used to steer the snowboard (Fig. 29.5)
5.4. **Snowboard standard** - A standard used to constrain the snowboard (Fig. 29.6 and App. 28).
Appendix 30
Method of Validation – Lab Test (Limiter)
In this appendix the method of validation of the seat construction can be found.

**Validation experiment**

### 1. Introduction

Earlier prototypes showed that the seat construction helps the COM to be placed over the edge of the snowboard in order to make a turn. The limiters are used to do this, in order to verify the working principle of SnowGo the amount of twist of the limiters is compared with MINI’s amount of twist.

The test described in this document is used to verify the following hypothesis;

**Hypothesis:**

1.1. In order to tilt SnowGo's limiters 10 degrees, the same or less weight is needed as compared to MINI's limiters.

### 2. Materials

Materials needed for these test are listed below;

2.1. SnowGo seat-construction - new prototype created by Michelle Hoogwout
2.2. MINI seat-construction - prototype created by Prodaptive
2.3. Snowboard – to screw seat-constructions on; Atomic Piq, learn to ride snowboard, with a length of 1.55 m
2.4. Weight – at least 100 kg to apply force (measurement weight, counter weight)
2.5. Level – to measure tilt angle of board
2.7. Rope – to attach weight to the prototype (make sure the same rope is used during the entire procedure)

### 3. Setup procedure

The setup should comply with the following guidelines

3.1. Place the snowboard inside the standard in a horizontal position (Fig. 30.1). This construction will restrain the board at the middle.
3.2. Place the Camera 7 meters away from the measure board facing the snowboard
3.3. Place counter weight on the snowboard standard to keep it from tilting (Fig. 30.1)

![Figure 30.1 – Placement of the weights on measurement set-up](image)
Record the following information on the data form

3.3.1. Organization, address, phone, and test administrators
3.3.2. Date, time, location
3.3.3. Take photographs of the object, the test environment, and the test set up

4. Collect Deflection Measurements

The limiters will be tested tilting towards the heel side and tilting towards the toe side. These two positions conclude one test, this test needs to be performed twice; once with prototype MINI and once with SnowGo.

4.1. Heel side tilting

4.1.1. DM₁ will be the relaxed position of the snowboard in the construction

4.1.1.1. Measure the tilt angle of the snowboard-standard, the vertical sitting tube, the horizontal sitting tube, and the limiters with an inclinometer at specified places (Fig. 30.1).

4.1.2. DM₂ will be the weighted position of the board in the standard

4.1.2.1. Attach 1 kg to position A by means of rope, and measure the tilt angle of the limiters. Continue this procedure and stop when the tilt angle of the limiters reads a 10 degrees difference from the unloaded tilt angle.

4.1.2.2. Measure the tilt angle of the base plate, the snowboard-standard, the vertical sitting tube, the horizontal sitting tube, and the limiters with an inclinometer at specified places (Fig. 30.1).

4.1.2.3. Write down the amount of weight put on the seat-construction.

4.2. Toe side tilting

4.2.1. DM₁ will be the relaxed position of the snowboard in the construction

4.2.1.1. Measure the tilt angle of the snowboard-standard, the vertical sitting tube, the horizontal sitting tube, and the limiters with an inclinometer at specified places (Fig. 30.1).

4.2.2. DM₂ will be the weighted position of the board in the standard

4.2.2.1. Attach 1 kg to position B by means of rope, and measure the tilt angle of the limiters. Continue this procedure and stop when the tilt angle of the limiters reads a 10 degrees difference from the unloaded tilt angle.

4.2.2.2. Measure the tilt angle of the base plate, the snowboard-standard, the vertical sitting tube, the horizontal sitting tube, and the limiters with an inclinometer at specified places (Fig. 30.1).

4.2.2.3. Write down the amount of weight put on the seat-construction.

4.3. Calculate the difference between MINI and SnowGo by subtracting the weight used on SnowGo’s seat construction from the weight used on MINI’s seat construction.

The calculation of difference is determined by:

\[
\text{Difference} = \text{Weight}_{\text{SnowGo}} - \text{Weight}_{\text{MINI}} \quad [\text{eq. 30.1}]
\]

4.3.1. If the calculated difference result is negative, the weight put on SnowGo’s seat construction was less than the weight put on MINI’s seat construction.
5. **Terminology - definitions**

5.1. **SnowGo** – New prototype, created by Michelle Hoogwout (Fig. 30.2, App. 27).

5.2. **MINI** – Former prototype created by Prodaptive (Fig. 30.3).

5.3. **Seat-construction** – seat and tube constructions used to attach the seat to the snowboard (Fig. 30.4).

5.4. **Snowboard standard** - a standard used to constrain the snowboard (Fig. 30.5, App. 28)
Appendix 31
Method of Validation – Lab Test (subjects)
In this appendix the method of validation of the snowboarding abilities on land can be found.

**Validation experiment**

1. **Introduction**

Earlier research showed that the placement of the center of mass (COM) determines the ability for a sit-snowboard to snowboard. If the COM can be placed over the edges of the snowboard the sit-snowboard can be used to snowboard with.

In order for sit-snowboarders to comfortable use the new prototype SnowGo it should not take up a lot of time to enter and exit a chairlift. Therefore some tests are performed to verify the time required to get into the chairlift position.

The safety within a chairlift is determined by the tilt of the upper body and the placement of the COM. When the COM is placed beyond the edge of the chairlift chair the subject will fall out of the chairlift if no further restrictions to their positions are used. In order to verify the position of the COM with different tilt angles of the upper body a reconstruction of the chairlift was created.

The tests described in this document are all used to verify the following hypotheses;

**Hypotheses:**

1.1. SnowGo allows the sit-snowboarder to place a projection of the center of mass (COM) over the edge of the snowboard.  
1.2. SnowGo’s handlebar can be taken out and put in in less than 2 minutes total  
1.3. The sit-snowboarder can change the sitting position for the use in the chairlift  
1.4. SnowGo allows the sit-snowboarders upper-body to sit-up straight without the loss of balance in the chairlift

2. **Materials & people**

Materials needed for these test are listed below;

2.1. SnowGo incl. snowboard – new prototype created by Michelle Hoogwout, incl: Atomic Piq, learn to ride snowboard, with a length of 1.55 m  
2.2. 1 camera incl. memory and battery packs – to record procedure  
2.3. 1 tripod – to keep the camera in place  
2.4. Athletics tape – to create marker points  
2.5. Sharpie – to create marker points  
2.6. 1 thick mat - to land on  
2.7. Timer – to record times needed to perform certain tasks  
2.8. Tape measure – to measure upper leg length  
2.9. Chairlift construction – for chairlift tests (App. 28)  
2.10. Table – to place chairlift construction onto  
2.11. Level – to measure tilt angle of upper leg

People needed for these test are listed below;

2.12. Test-coach - Person to guide people through tests  
2.13. Engineer – Person to switch test set-ups  
2.14. Test-administrator – Person to write down progression and things said

The task of both the Engineer and test-coach can be combined into one person.
3. Setup procedure

The setup should comply with the following guidelines for the different tests;

3.1. For **test 1, 2 and 3**;
   3.1.1. Place the snowboard on the floor (Fig. 3.1). And place markers on 3 places the floor to determine the exact position of the snowboard so that it can be placed in the exact same spot during each part of the test.
   3.1.2. Place a thick mat on one side of the board (Fig. 3.1)

![Figure 3.1– measurement set-up test 1](image1)

3.2. For **test 4**;
   3.2.1. Place the chairlift construction on a table and attach with two clamps (lijnklemmen).
   3.2.2. Take the two handlebars out of their socket and place the sit-snowboard in the chairlift position. Then place it on the chairlift set up between the two red lines (Fig. 3.2).

*Note: make sure that when SnowGo is placed on the table the snowboard is at least 15 cm of the floor.*

![Figure 3.2– Measurement set-up test 3; A) chairlift set up 3, B) test subject on test set up 3](image2)

3.2.3. Place the camera 7 meters away from the sit-snowboard facing the snowboard.
3.3. Record the following information on the data form

3.3.1. Organization, address, phone, and test administrators
3.3.2. Date, time, location
3.3.3. Take photographs of the object, the test environment, and the test set up

4. Testing Environment – Laboratory

The test environment will be a laboratory environment.

4.1. Testing Environment Setup – The environment in which the measurements are conducted should be able to sustain the same lighting conditions for the duration of the test. If there are windows, the shades should be drawn to prevent a change in the light filtering in through the windows.

4.2. Lighting Requirements – The testing environment should be illuminated enough to use a diaphragm of F5.6 or higher. This means that the minimum range the testing environment should be illuminated at during the measurements is 10 to 15 footcandles or 100 to 160 lux.

4.2.1. Record both the illumination level and the diaphragm used on the data form

4.3. Camera Requirements – The camera used during testing should shoot at least 21 images per second and have a minimum focal length of 136 mm.

4.3.1. Set the camera at a distance of 7 meters from the test set up
4.3.2. Set the camera on a tripod at a height of 1 meter from the ground surface
4.3.3. Zoom in, making sure the snowboard, standard, and the sit-snowboarder are still fully in the picture/focus
4.3.4. Write down the zoom settings, as can be seen on the screen of the camera

5. Subjects

The subject participating to these test complied to the following criteria;

5.1. 8 male and 4 female snowboarders
5.2. All subjects were in the range of 20-26 years old, were in the range of 1.63-1.91 m in length, and had 0-95 days of experience.
5.3. None of them had any conditions that negatively affect the upper or lower extremities.
5.4. All subjects signed a consent form after being informed about the procedure and prior to participation in the experiment.

6. Test Procedure and instruction

6.1. Pre-testing procedure – Before the test started the subjects were informed on the tests to be done, a text was set-up and verbally explained to the subjects (App. 32). After this instruction subjects were asked to sign a consent form. Then the personal data was noted and the upper leg was measured.

6.1.1. Personal data - write down; Name, age in years, weight in kilograms, length in meters, snowboard experience in days.
6.1.2. Measuring length of the upper leg – Sit the test-person down on a stool, close to a wall, and let him/her put their buttocks up to the wall. Let
the test person hold a hip-wide piece of wood up to the knees, and let them use their leg muscles to get the upper leg in a horizontal +/- 2 degrees position (measure with level) (Fig. 31.3). Then measure the distance from the wall to the knees with a tape measure.

![Figure 31.3](image)

Figure 31.3 – Method to measure the length of the upper leg of the test subjects

### 6.1.3. Placement of the markers

Markers were placed on the clothing of the test subjects. The markers should be placed on the place of the following bony landmarks; On the tuberculum majus, on the crista iliaca right above the trochanter major, and on the joint space of the art. Genus (Fig. 31.4).

![Figure 31.4](image)

Figure 31.4 – Placement of the markers on bony landmarks; A) on the tuberculum majus, B) on the crista iliaca right above the trochanter major, and C) on the joint space of the art. Genus. Exact spot is marked with an arrow.

### 6.2. Test 1

SnowGo was placed in the test set-up (section 3.1), then the test subject was placed inside SnowGo. The subject was instructed to shift his/her weight from the neutral position to the toe-side edge of the snowboard. The subject was specifically instructed to do this in a controlled manner and in 3-5 seconds. Once the subject moved his/her center of mass (COM) past the edge of the board the snowboard started tilting resulting in a fall of both the subject and the test-set up. To prevent this from happening the test-coach would guide the subject through this process. The point of falling could be recognized by letting the test-subject fall about 10 cm before catching them in their fall, for safety reasons the thick mats where used to land on. After the toe side falling repetitions the snowboard was turned 180 degrees (nose to tail and tail to nose) to make sure that the thick mat was on the heel side of the snowboard and the
procedure was repeated and the subject was asked to tilt his/her weight from a neutral position to the heel side edge of the snowboard.

6.3. **Test 2** - Then the subject was instructed to take out the handlebar and put it back in, a timer was used to measure the time needed to do so. When the handlebar was taken out the timer would be started when the subjects had his/her hands on the handlebar, and would be stopped when the upper part was completely out of the lower part. When the handlebar was put back in the timer would be started when the upper part was at 5-10 cm away from the lower part and would be stopped when the locking mechanism clicked into the lower part.

The subjects would practice 2 times and then be recorded 3 times.

6.4. **Test 3** - The subject was instructed to turn into the chairlift mode, by switching from the snowboard mode to the chairlift mode.

6.5. **Test 3** - The last task involved a reconstruction/model of a ski-lift which will lift the snowboard at least 15 cm off the floor. One camera was placed lateral to the sit-snowboarder and set-up. That camera was focused on both the sit-snowboarder and the snowboard (Fig. 31.2). The prototype was placed on this ski-lift and then the subject was asked to lean forward in a controlled manner, in 3-5 seconds, until tilting. Again the test-coach would guide the test subject.

7. **Time schedule**

7.1. In session 1 the intention was to verify the ability to project the COM over the edge of the board. This was done by testing the ability to tilt the board over one of edges.

**Test 1**

<table>
<thead>
<tr>
<th>Time [min]</th>
<th>Task</th>
<th>No. of repetitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00-1.00</td>
<td>Move body weight from neutral position to toe side in 3-5 seconds with hands on the handlebars</td>
<td>2</td>
</tr>
<tr>
<td>1.00-2.00</td>
<td>Move body weight from neutral position to toe side in 3-5 seconds with the hands free from the handlebars</td>
<td>2</td>
</tr>
<tr>
<td>3.00-4.00</td>
<td>Turn snowboard 180 degrees</td>
<td>x</td>
</tr>
<tr>
<td>4.00-5.00</td>
<td>Move body weight from neutral position to heel side in 3-5 seconds with hands on the handlebars</td>
<td>2</td>
</tr>
<tr>
<td>5.00-6.00</td>
<td>Move body weight from neutral position to heel side in 3-5 seconds with the hands free from the handlebars</td>
<td>2</td>
</tr>
<tr>
<td>6.00-7.00</td>
<td>Rest/spare time</td>
<td>x</td>
</tr>
</tbody>
</table>

7.2. In session 2 the intention was to measure the time needed to get 'chairlift-ready'.

**Test 2**

<table>
<thead>
<tr>
<th>Time [min]</th>
<th>Task</th>
<th>No. of repetitions</th>
</tr>
</thead>
<tbody>
<tr>
<td>7.00-16.00</td>
<td>Take out handlebar and put back in; 2 test runs, and 3 recorded runs</td>
<td>5</td>
</tr>
<tr>
<td>16.00-18.00</td>
<td>Change sitting position to from snowboard to chairlift position</td>
<td>1</td>
</tr>
<tr>
<td>18.00-20.00</td>
<td>Rest/change set-up</td>
<td>x</td>
</tr>
</tbody>
</table>
7.3. In session 3 the intention was to determine the amount of tilt of the upper body that can be done before the COM goes beyond the chairlift chair.

**Test 3**

<table>
<thead>
<tr>
<th>Time [min]</th>
<th>Task</th>
<th>No. of repetitions per position</th>
</tr>
</thead>
<tbody>
<tr>
<td>20.00-23.00</td>
<td>Sit on chairlift reconstruction and lean forward in 3-5 seconds; 2 positions were used in the chairlift; in the first the knees would be pushed into the knee pads and in the second the buttocks would be placed as far back as possible into the seat.</td>
<td>2 per position</td>
</tr>
</tbody>
</table>

8. **Terminology – definitions**

8.1. **SnowGo** – New prototype, created by Michelle Hoogwout (Fig. 31.5, App. 27).

8.2. **Handlebar** - tube constructions used to steer the snowboard (Fig. 31.6).

8.3. **Seat-construction** – seat and tube constructions used to attach the seat to the snowboard (Fig. 31.7).

8.4. **Center of mass (COM)** – the location at which the resultant force, of the forces of gravity acting on a body, acts [31.1] (Fig. 31.8).

8.5. **Toe-side** – side of the board which the toes are closest to (Fig. 31.9).

8.6. **Heel-side** – side of the board which the heels are closest to (Fig. 31.10).

8.7. **Test coach** – a person who guides the test subjects through the tests

8.8. **Chairlift construction** – construction designed to represent a chairlift seat (Fig. 31.12, App. 28).

References

Appendix 32
Test Explanation
In this Appendix the information given to each test person for the lab test with test subjects can be found.

Het product dat hier naast je staat is het nieuwe ontwerp van een zit-snowboard. Vandaag gaan we een paar testen uitvoeren die bepalen of het hypothetisch/physiek gezien mogelijk is om met dit ontwerp te snowboarden. Ook gaan we kijken of het mogelijk is voor jou, als gebruiker, om het zit-snowboard klaar te maken voor gebruik in een stoeltjeslift. Dit gaan we allemaal testen aan de hand van 3 test opstellingen die zullen worden gefilmd, maar eerst zal ik, Michelle Hoogwout, wat gegevens van je noteren. Het gaat hier om je leeftijd, lengte en gewicht. Ook zullen we zo je bovenbeen lengte gaan meten.

Daarna zullen we op zowel je schouder als knie een stukje sporttape met een stip erop aanbrengen, dit zijn markers die ons later bij het analyseren van de videobeelden zullen helpen met het bepalen van lichaamspunten.

**De drie testen:**

In de *eerste test* gaan we valtesten doen. Tijdens het snowboarden is het belangrijk dat jij, de gebruiker, je gewicht over de kanten kan leggen zodat je het board kan laten kantelen. Dit is belangrijk bij het maken van bochten en dus het sturen van het board. Om dit te testen zullen we je vragen om in het zit-snowboard plaats te nemen en je voorover op een mat te laten vallen. Daarna zullen we dit achterover herhalen. Gezien het feit dat de mat iets hoger is val je niet zo diep en zal pijn bij het opvolgen van de volgende tips uitblijven. Tijdens onze testen gaat het erom dat je langzaam valt zodat je niet je beweging gebruikt bij het vallen maar echt je gewicht, we zullen je dan ook vragen om in 3-5 seconden met een zo recht mogelijke romp naar voren te scharnieren vanuit de heupen totdat je valt. Aangezien het kantelen voor ons belangrijk is en niet het echte vallen of de landing maakt het voor ons niet uit wat jij uit reflex doet, dus maak je daar geen zorgen over. Wat voor ons wel belangrijk is is dat je je niet bezeert, probeer tijdens het vallen niet je handen uit te steken maar juist dicht bij je lichaam te houden, zie foto’s.

![Foto 1: Armen van je af](image1.jpg)  ![Foto 2: Armen dicht bij](image2.jpg)

Bij het achterwaartse vallen kan dit eng aanvoelen, Michelle kan je dan ook helpen door je na een korte val van plus minus 10 cm tegen te houden als je dit verkiest.

Voor de *tweede test* gaan we naar de armsteunen en het klaarmaken van het prototype voor het zitten in de skilift. We zullen je vragen om de armsteun met de fietsrem in en
uit zijn steun te halen. Verder vragen we je om de andere armsteun zo strak mogelijk aan te draaien en dan met al je kracht proberen die uit zijn steun te halen. Als laatste zal er voor deze test gevraagd worden of je je zit-positie kan draaien door de pin omhoog te halen. (Michelle doet dit zo voor)

Voor de **derde en laatste test** gebruiken we de ski-lift opstelling, hier zullen we het zit-snowboard op de tafel positioneren en je wederom vragen om je lichaam in 3-5 seconden vanuit de heupen naar voren te scharmieren. Je zult dan naar voren gaan kantelen en hiermee is de test dan ook ten einde. Dit keer zal je niet vallen maar door het board worden tegengehouden, aangezien je leunt op de punt vragen we je om niet verder door te leunen aangezien de punt hierdoor kan breken.

De testen zullen nog een keer worden uitgelegd voor het afnemen van de respectievelijke testen. Bedenk je verder goed dat jij niets fout kan doen, de testen zijn puur om te kijken of er dingen mogelijk zijn; hierin kan alleen het ontwerp falen niet jij. Succes!
Appendix 33
Method of Validation – Field test (Sit-snowboarding)
In this appendix the method of validation of the snowboarding abilities in the snow can be found.

Validation experiment
1. Introduction

In order to compare the working of SnowGo with MINI in the snow this test was created. Both the prototypes will be compared in performance by looking at snowboarding maneuvers like skidding and the performed turns at indoor snowsport facility Snowworld Zoetermeer.

The tests described in this document are all used to verify the following hypotheses;

Hypotheses:

1.1. Falling angle – The angle needed to fall on either the toe side or the heel side with SnowGo is smaller than the angle needed to fall on either the toe side or the heel side with MINI
1.2. Falling leaf – number of skidded-turns without falling with SnowGo are equal to or more than the number of skidded-turns with MINI
1.3. Straight skidding – the amount of deviation from straight with SnowGo is equal or less than the deviation with MINI
1.4. Steering a turn – the amount of deviation from the pawn/the perfect board line with SnowGo is equal or less than the deviation with MINI

2. Materials & people

Materials needed for these test are listed below;

2.1. SnowGo with snowboard – new prototype created by Michelle Hoogwout, incl board; Atomic Piq, learn to ride snowboard, with a length of 1.55 m
2.2. MINI with snowboard – Prototype created by Prodaptive, incl board; Atomic Piq, learn to ride snowboard, with a length of 1.55 m
2.3. 1 camera’s incl. memory and battery packs – to record procedure
2.4. 1 tripod – to keep the camera in place
2.5. Tape measure – to record deviations
2.6. Pawns – to set out the course/line of action

People needed for these test are listed below;

2.7. Test-coach - Person to guide people through tests; this persons needs to have a minimum of teaching 10 lessons in adaptive sit-snowboarding
2.8. Engineer – Person to switch test set-ups
2.9. Test-administrator – Person to write down progression and things said

The task of both the Engineer and test-administrator can be combined into one person.

3. Setup procedure

The setup should comply with the following guidelines for the different tests;

3.1. For test 1; (Falling test)
3.1.1. Place the snowboard on the snow and place markers on 3 places in the snow to determine the exact position of the snowboard so that it can be placed in the exact same spot during each part of the test.

3.1.2. Set up the camera in line and eight meters away from the snowboard, pointing towards the snowboard.

3.2. For **test 2**; (Falling leaf)

3.2.1. Set up four pawns in the configuration found in Figure 33.1

3.3. For **test 3**; (Straight skidding)

3.3.1. Set up four pawns in the configuration found in Figure 33.2

3.4. For **test 4**; (Turn initiation)

3.4.1. Set up four pawns in the configuration found in Figure 33.3

3.5. Record the following information on the data form

3.5.1. Organization, address, phone, and test administrators

3.5.2. Date, time, location

3.5.3. Take photographs of the object, the test environment, and the test set up

---

4. **Subjects**

The subject participating to these test complied to the following criteria;

4.1 1 male and 1 female snowboarders, with a minimum of 21 days of experience, participated in the experiment.

4.2 The female subject was 20 years old, with a length of 1.72 m, a weight of 58 kg, and 30 days of snowboarding experience, and the male subject was 25 years of age, with a length of 1.86 m, a weight of 80 kg, and 25 days of snowboarding experience.

4.3 None of them had any conditions that negatively affect the upper or lower extremities.

4.4 All subjects signed a consent form after being informed about the procedure and prior to participation in the experiment.
5. Test Procedure

The entire test procedure consisted of 4 sessions; 1) falling, 2) falling leaf, 3) straight skidding, and 4) turn initiation. Before each test session started the procedure was explained to the test subjects. Any questions were answered before the procedure would start.

6. Task Instruction & time schedule

The task instruction was as follows for the different tests.

6.1. For test 1; (Falling test)
   6.1.1. The subject was instructed to shift his/her weight from the neutral position to the toe-side edge of the snowboard. The subject was specifically instructed to do this in a controlled manner and in 3-5 seconds. Once the subject moved his/her center of mass (COM) past the edge of the board the snowboard started tilting resulting in a fall of both the subject and the test setup. To prevent this from happening the test-coach would guide the subject through this process. The point of falling could be recognized by letting the test-subject fall about 10 cm before catching them in their fall. After the toe side falling repetitions the snowboard was turned 180 degrees (nose to tail and tail to nose) and the procedure was repeated and the subject was asked to tilt his/her weight from a neutral position to the heel side edge of the snowboard.

6.2. For test 2; (Falling leaf)
   6.2.1. During this test the sit-snowboarder will stay on either the heel or the toe side edge and will skid down the slope traversing from left to right following a path (Fig. 33.1). Each traverse switch needs to be made between alternating the right and the left side cones.

6.3. For test 3; (Straight skidding)
   6.3.1. During this test the subjects should try to move the snowboard sideways down the slope in a straight line (Fig. 33.2).

6.4. For test 4; (Turn initiation)
   6.4.1. In this test the subjects would sit-snowboard straight down the slope starting from the starting cones until the initiation cone is reached (Fig. 33.3). Once the initiation cone was reached the sit-snowboarder would initiate a turn and try to end as close to the target cone as possible.

In this test the time schedule is not leading, since it cannot be said that a test will be exactly a certain amount of minutes, the maximum length of the time period without rest is however a set time since the concentration and exhaustion of the sit-snowboarder will determine further results. A five minute break will follow after every time period of one hour, after 3 hours there was a lunch break.
### Time schedule:

<table>
<thead>
<tr>
<th>Session</th>
<th>Time</th>
<th>Task</th>
<th>surface lift/turning</th>
<th>Break</th>
<th>No. repetitions of task</th>
<th>Type of board</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>MINI SnoGo</td>
</tr>
<tr>
<td>1</td>
<td>5 min</td>
<td>alternating body weight – feeling weight shift</td>
<td>X</td>
<td></td>
<td>2 toe side/ 2 heel side</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5 min</td>
<td>alternating body weight – feeling weight shift</td>
<td>X</td>
<td></td>
<td>2 toe side/ 2 heel side</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15 min</td>
<td>alternating body weight – fall test (without holding handlebars)</td>
<td>X</td>
<td></td>
<td>2 toe side/ 2 heel side</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15 min</td>
<td>alternating body weight – fall test (without holding handlebars)</td>
<td>X</td>
<td></td>
<td>2 toe side/ 2 heel side</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20 min</td>
<td>Skidding heel side – practice</td>
<td>3 min</td>
<td></td>
<td>1 toe side/ 1 heel side</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30 min</td>
<td>Skidding heel side – falling leaf</td>
<td>3 min</td>
<td></td>
<td>2 toe side/ 2 heel side</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20 min</td>
<td>Skidding toe side – practice</td>
<td>3 min</td>
<td></td>
<td>1 toe side/ 1 heel side</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30 min</td>
<td>Skidding toe side – falling leaf</td>
<td>3 min</td>
<td></td>
<td>2 toe side/ 2 heel side</td>
<td></td>
</tr>
<tr>
<td></td>
<td>total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>152 min</td>
</tr>
<tr>
<td></td>
<td>Break</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>60 min</td>
</tr>
<tr>
<td>2</td>
<td>30 min</td>
<td>Skidding heel side – straight</td>
<td>3 min</td>
<td></td>
<td>2 toe side/ 2 heel side</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30 min</td>
<td>Skidding toe side - straight</td>
<td>3 min</td>
<td></td>
<td>2 toe side/ 2 heel side</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30 min</td>
<td>Turn initiation – with pawn</td>
<td>3 min</td>
<td></td>
<td>2 left side/ 2 right side</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30 min</td>
<td>Turn initiation – with pawn</td>
<td>3 min</td>
<td></td>
<td>2 left side/ 2 right side</td>
<td></td>
</tr>
<tr>
<td></td>
<td>total</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>132 min</td>
</tr>
<tr>
<td>Grand total time:</td>
<td>5 hours 44 min</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The second test person will alternate the prototypes in exactly the other way so that test person 1 and test person 2 can do the tests at the same time.

7. **Measurements**

7.1. For **test 1**; (Falling test)

7.1.1. All trials were recorded with a camera, the frame prior to the frame in which the snowboard started tilting (24 frames per sec.) was put in Photoshop (Adobe Photoshop CS5.1 (64 Bit)) and the Ruler tool was used to measure the angle between the vertical and the upper body (Fig. 33.4).
7.2. For test 2; (Falling leaf)
   7.2.1. Count the number of traverse switches (Fig. 33.1).
7.3. For test 3; (Straight skidding)
   7.3.1. Measure the deviation from straight (d) (Fig. 33.2).
7.4. For test 4; (Turn initiation)
   7.4.1. Measure the deviation from the ‘perfect’ turn line (p) and the deviation from the target cone (c) (Fig. 33.3).

8. Terminology – definitions

8.1. SnowGo – New prototype, created by Michelle Hoogwout (Fig. 33.1).
8.2. MINI – Former prototype created by Proadaptive (Fig. 33.2).
8.3. Handlebar – tube constructions used to steer the snowboard (Fig. 33.3).
8.4. Seat-construction – seat and tube constructions used to attach the seat to the snowboard (Fig. 33.4).

8.5. Center of mass (COM) – the location at which the resultant force, of the forces of gravity acting on a body, acts [33.1] (Fig. 33.5).
8.6. Toe-side – that side of the board where the toes are closest to (Fig. 33.6).
8.7. Toe-side turn – turn made on the toe side
8.8. Heel-side – that side of the board where the heels are closest to (Fig. 33.7).
8.9. **Heel-side turn** - turn made on the heel side

8.10. **Test coach** - a person who guides the test subjects through the tests

8.11. **Connected turns** - when heel-side and toe-side turns are connected one into the other

8.12. **Skidded turn** - Turns where the tail of the board does not follow the same path as the tip of the board. Leaves snow spray, making smeared marks. These turns are for the less experienced boarders and create braking forces which slows the boarder down (Fig. 33.8). [33.2]

8.13. **Falling leaf** - The Falling Leaf is named because the movement of the boarder will resemble the movement of a leaf as it falls from a tree. The objective of this drill is to introduce movements that will allow the athlete to begin changing direction while controlling his or her speed (Fig. 33.1). [33.3]

8.14. **Set-up turn initiation test** - The set-up of the turn initiation test (Fig. 33.3).

8.15. **Set-up straight skidding test** - The set-up of the straight skidding test (Fig. 33.2).

**References**


[33.3] sports [Web page], [cited 2013, 12-2013], available from http://sports.specialolympics.org/specialo.org/Special /English/Coach/Coaching/Snowbo ar/Teaching/Falling_3.htm
Appendix 34
Method of Validation – Field test (Chairlift)
In this appendix the method of validation of the abilities to ride the chairlift can be found.

**Validation experiment**

1. **Introduction**

To verify the chairlift compatibility of SnowGo the prototype was tested in Snowworld Landgraaf, where one chairlift can be found on the slope.

**Hypothesis:**

1.1. The sit-snowboarder can maneuver a chairlift with SnowGo, without falling.

*Note: SnowGo would pass the test if 2 out of 5 trials could be performed without falling*

2. **Materials & people**

Materials needed for these test are listed below;

2.1. SnowGo with snowboard – new prototype created by Michelle Hoogwout, incl board; Atomic Piq, learn to ride snowboard, with a length of 1.55 m

People needed for these test are listed below;

2.2. Test-coach - Person to guide people through tests

The task of both the Engineer and test-administrator can be combined into one person.

3. **Setup procedure**

Record the following information on the data form

3.1. Organization, address, phone, and test administrators

3.2. Date, time, location

3.3. Take photographs of the object, the test environment, and the test set up

4. **Subjects**

The subject participating to these test complied to the following criteria;

4.1 1 male sit-snowboarder participated in the experiment. A minimum of 10 days sit-snowboarding experience is needed during these tests.

4.2 The male subject was 28 years of age, with a length of 1.76 m, a weight of 95 kg, and 10 days of sit-snowboarding experience.

4.3 All subjects signed a consent form after being informed about the procedure and prior to participation in the experiment.

5 **Test Procedure**

The entire test procedure consisted out of five trials; before the test started, the procedure was explained to the test subject. Any questions were answered before the procedure would start. The subject was instructed to sit as far back in the snowboard seat as he could and to lean backward to hold the back of the chairlift when loading the chairlift. When unloading the chairlift the test subjects were instructed to lean forward after the snowboard touched the snow, then push themselves forward to make sure that
the chairlift chair was behind the snowboard seat. This was done to make sure that the snowboard would not be re-loading the chairlift at the top at the turning point of the chairlift.

6. Task Instruction & time schedule

In this test the time schedule is not leading, since we cannot say that a test will be exactly a certain amount of minutes, the maximum length of the time period without rest is however a set time since the concentration and exhaustion of the sit-snowboarder will determine further results. A five minute break will follow after every hour, and a 60 min break will follow after every three hours. The second step of the test-procedure, taking the chairlift up without any help, was only performed when the test subject and test coach would feel confident about the chairlift ride based on the chairlift rides with the test coach.

**Time schedule:**

<table>
<thead>
<tr>
<th>Time</th>
<th>Task</th>
<th>Getting down the slope</th>
<th>No. repetitions of task</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 min</td>
<td>taking chairlift up – with test coach</td>
<td>20 min</td>
<td>2</td>
</tr>
<tr>
<td>15 min</td>
<td>taking chairlift up – without any help</td>
<td>20 min</td>
<td>3</td>
</tr>
<tr>
<td><strong>total</strong></td>
<td><strong>175 min</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

7. Terminology – definitions

7.1. **SnowGo** – New prototype, created by Michelle Hoogwout (Fig. 34.1)

![Figure 34.1 – SnowGo](image)

7.2. **Test coach** - a person who guides the test subjects through the tests
Appendix 35
Test results
An overview of all the test results of the different tests can be found in the following text.

**Dry tests – Dead weight**

The dead weight tests were divided into two sessions; (1) a test for the handlebars, and (2) a test for the seat/limiter function. For both sessions hypotheses were verified.

For the Handlebar the hypothesis was:

1. In order to tilt the board 10 degrees, less weight has to be used using SnowGo than using MINI.

<table>
<thead>
<tr>
<th></th>
<th>Loaded forward [kg]</th>
<th>Loaded backward [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>SnowGo</td>
<td>23</td>
<td>26</td>
</tr>
<tr>
<td>MINI</td>
<td>28</td>
<td>39.25</td>
</tr>
</tbody>
</table>

After performing the tests it seems that the hypotheses was true. In order to tilt the snowboard tip 10 degrees forward, SnowGo’s handlebar needed 23 kg and MINI’s handlebar needed 28 kg. To tilt the snowboard tip 10 degrees backward, SnowGo’s handlebar needed 26 kg and MINI’s handlebar needed 39.25 kg. These tests have only been performed once so further research should be done to determine the significance of these results.

For the Seat the hypothesis was:

1. In order to tilt SnowGo’s limiters 10 degrees, the same or less weight is needed as compared to MINI’s limiters.

<table>
<thead>
<tr>
<th></th>
<th>Loaded forward [kg]</th>
<th>Loaded backward [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>SnowGo</td>
<td>15</td>
<td>13.5</td>
</tr>
<tr>
<td>MINI</td>
<td>73.75</td>
<td>24</td>
</tr>
</tbody>
</table>

After performing the tests it seems that the hypotheses was true. In order to tilt the limiter 10 degrees forward, SnowGo’s knee pads needed 15 kg and the weight on MINI’s knee pads was 73.75 kg. To tilt the limiter 10 degrees backward, SnowGo’s seat needed 13.5 kg and the weight on MINI’s knee pads was 24 kg. The difference in weight does imply a great difference between the snowboard performance of SnowGo as compared to MINI. Especially toe side will be very different in use. However since snowboarding on the toe side is difficult with MINI, it was chosen to keep the rubbers in the limiters used during these tests. Snow-tests will have to show whether or not this ease of tilting is preferable. These tests have only been performed once so further research should be done to determine the significance of these results.
Dry tests – Test subjects

The dry tests with test subjects, had multiple hypothesis which had to be verified. These hypotheses were:

1. SnowGo allows the sit-snowboarder to place a projection of the center of mass (COM) over the edge of the snowboard.
2. SnowGo’s handlebar can be taken out and put in in less than 2 minutes total
3. The sit-snowboarder can change the sitting position for the use in the chairlift
4. SnowGo allows the sit-snowboarders upper-body to sit-up straight without the loss of balance in the chairlift

The test subjects had an average age of 23.5 (st. dev. 1.73 years) and their average weight was 70.8 (st. dev. 8.63 kg).

<table>
<thead>
<tr>
<th>Test subject no.</th>
<th>length [m]</th>
<th>Length upper leg [cm]</th>
<th>Average time to take handlebar [sec]</th>
<th>Average time to put in handlebar [sec]</th>
<th>Average Falling angle knees [deg]</th>
<th>Average Falling angle back [deg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1,63</td>
<td>55</td>
<td>3,7</td>
<td>5,7</td>
<td>-13</td>
<td>15,5</td>
</tr>
<tr>
<td>2</td>
<td>1,86</td>
<td>59</td>
<td>4,3</td>
<td>3,7</td>
<td>-4</td>
<td>9</td>
</tr>
<tr>
<td>10</td>
<td>1,68</td>
<td>59,5</td>
<td>1,7</td>
<td>5,3</td>
<td>-8</td>
<td>13</td>
</tr>
<tr>
<td>11</td>
<td>1,75</td>
<td>59,5</td>
<td>1,7</td>
<td>1,7</td>
<td>-7,5</td>
<td>3,5</td>
</tr>
<tr>
<td>8</td>
<td>1,72</td>
<td>60</td>
<td>2,7</td>
<td>1,7</td>
<td>-5,5</td>
<td>20,5</td>
</tr>
<tr>
<td>5</td>
<td>1,83</td>
<td>60,5</td>
<td>2,7</td>
<td>5</td>
<td>-1</td>
<td>15,5</td>
</tr>
<tr>
<td>2</td>
<td>1,8</td>
<td>61,5</td>
<td>3,7</td>
<td>4</td>
<td>2</td>
<td>8,5</td>
</tr>
<tr>
<td>3</td>
<td>1,8</td>
<td>62</td>
<td>1</td>
<td>1,7</td>
<td>-2,5</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>1,91</td>
<td>65</td>
<td>3</td>
<td>2,3</td>
<td>14,5</td>
<td>17</td>
</tr>
<tr>
<td>7</td>
<td>1,84</td>
<td>65</td>
<td>2</td>
<td>2</td>
<td>4,5</td>
<td>14</td>
</tr>
<tr>
<td>6</td>
<td>1,85</td>
<td>66</td>
<td>3</td>
<td>2</td>
<td>8,5</td>
<td>8,5</td>
</tr>
<tr>
<td>9</td>
<td>1,85</td>
<td>66</td>
<td>1,3</td>
<td>6,7</td>
<td>7,5</td>
<td>18</td>
</tr>
<tr>
<td>average</td>
<td>1,8</td>
<td>61,6</td>
<td>2,6</td>
<td>3,5</td>
<td>-0,4</td>
<td>12,3</td>
</tr>
<tr>
<td>st dev</td>
<td>0,08</td>
<td>3,37</td>
<td>1,04</td>
<td>1,82</td>
<td>8,00</td>
<td>5,36</td>
</tr>
</tbody>
</table>

The first hypothesis seemed to be true since every subject could fall forward and backward, meaning that their COM went beyond the edges of the snowboard.

The second hypothesis seemed to be true; the subjects needed an average time of 2.6 seconds (st. dev. 1.04 sec.) to take one handlebar out and an average of 3.5 seconds (st. dev. 1.82 sec.) to put on handlebar in.

The third hypothesis also seemed to be true, all subjects could turn from the snowboard towards the chairlift position.

The fourth hypothesis was tested and seemed to be conditionally true. Two situations were tested on the balance in a chairlift. In the first test the subjects would sit forward as much as possible by putting their knees firmly into the knee pads, in this situation not every subject could sit up straight without the loss of balance. In the second test the subject would sit back into the seat, in this situation all the subjects could sit up straight. They could even tilt their upper body forward, ranging from 1 to 23 degrees forward. The average forward tilting angle of the upper body found with this later test was 12.3 degrees (st. dev. 5.36 degrees). The Shapiro-Wilk and the Kolmogorov-Smirnov tests were used to verify the normal distribution of the data. A two-tailed paired t-test was performed (IBM SPSS Statistics version 23) to check the inter subject dependence of
the angle of the upper body between the results gathered from the two different sitting positions.

### Explore

#### Tests of Normality

<table>
<thead>
<tr>
<th></th>
<th>Kolmogorov-Smirnov(a)</th>
<th>Shapiro-Wilk</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Statistic</td>
<td>df</td>
</tr>
<tr>
<td>Mean_knee</td>
<td>.114</td>
<td>12</td>
</tr>
<tr>
<td>Mean_back</td>
<td>.150</td>
<td>12</td>
</tr>
</tbody>
</table>

* This is a lower bound of the true significance.

a. Lilliefors Significance Correction

Figure 35.1 – Test of normality (Sig.=p)

#### T-Test

<table>
<thead>
<tr>
<th>Paired Differences</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Std. Error Mean</th>
<th>Lower</th>
<th>Upper</th>
<th>t</th>
<th>df</th>
<th>Sig (2-tailed)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pair 1 Mean_knee-Mean_back</td>
<td>-12.763</td>
<td>8.3355</td>
<td>2.5595</td>
<td>-18.3222</td>
<td>-7.0046</td>
<td>-4.933</td>
<td>11</td>
<td>.000</td>
</tr>
</tbody>
</table>

Figure 35.2 – The output data of the t-test (p(Sig (2-tailed))<0.05 thus the data is significantly different)

A Shapiro-Wilk’s test (p>0.05) (Fig. 35.1)[35.1][35.2] and a visual inspection of their histograms, and box plots showed that the falling angel data was approximately normally distributed for both the knee angles and the back angles. The knee angles had a skewness of 0.341 (st. dev. 0.637) and a kurtosis of -0.500 (st. dev. 1.232), and the back angles had a skewness of -0.238 (st. dev. 0.637) and a kurtosis of -1.039 (st. dev. 1.232) [35.3][35.4][35.5]. The T-test then showed that the data was significantly different (p<0.05).

From this test two conclusions were taken; 1) the sit-snowboarder should sit back into the seat as far as possible when loading a chairlift; 2) when the sit-snowboarder sits back into the seat he/she can tilt forward significantly more (P=0.0004) than when he/she has his/her knees in the knee pads. The amount a subject can tilt forward seems to have to do with their fit into the snowboard. In the data it seems that the upper leg has an influence on the tilt angle; people with upper legs in the range of 65-66 cm can tilt forward independent of their position in the seat and knee pads, this is different for people in the range of 62-55 cm. Further research into this should determine whether the length of the upper leg has any significant influence on the tilt angle of the upper body.

**NOTE** – No firm conclusions can be made from this data since amount of test-subjects were insufficient. The implications done should therefore be verified with further research.
Preliminary snowboarding tests – Snowworld Zoetermeer

The snowboarding snow-tests, had multiple hypothesis which had to be verified. These hypotheses were:

1. Falling leaf – number of skidded-turns without falling with SnowGo are equal to or more than the number of skidded-turns with MINI
2. Straight skidding – the amount of deviation from straight with SnowGo is equal or less than the deviation with MINI
3. Steering a turn – the amount of deviation from the pawn/the perfect board line with SnowGo is equal or less than the deviation with MINI

Two test subject were used; 1) Male, 25 years of age, 80 kg, 1.86 m in length, with 25 days of experience in snowboarding, 2) Female, 20 years of age, 58 kg, 1.72 m in length, with 30 days of experience in snowboarding.

This test procedure was broken up in 4 exercises; 1) Fall tests, 2) Skidding – falling leaf tests, 3) Skidding – straight skidding tests, 4) steering a turn tests (App. 33).

The fall tests were performed to find out how the tests performed on land related to the tests in the snow, and to see the expected difference in performance with MINI and SnowGo. No dry tests were done with MINI.

<table>
<thead>
<tr>
<th>Heel side falling angle [deg]</th>
<th>Toe side falling angle [deg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>MINI</td>
<td>SnowGo</td>
</tr>
<tr>
<td>Dry test</td>
<td>MINI</td>
</tr>
<tr>
<td>test subject no.</td>
<td>1</td>
</tr>
<tr>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>x</td>
<td>6</td>
</tr>
</tbody>
</table>

The results seem to show that the snow and dry test show similar results, this seems to show that the dry tests are indeed a validation for the snowboard abilities of the prototype. The difference between the prototypes show that the subjects will have difficulty to use toe side with MINI, especially since the subjects would come out of their seats to make this kind of angle with their upper body. The heel side of MINI is however so easily reached, even without actually leaning back. This may mean two things; 1) the subjects are either within their comfort zone with these angles and can carefully maneuver the heel side of MINI, or 2) the subjects go onto heel side so easily that they fall over rather quick.

For the first hypothesis a falling leaf test was done.

<table>
<thead>
<tr>
<th>skidding falling leaf</th>
<th>Heel-side No. Of switches within lines without falling</th>
<th>Toe-side No. Of switches within lines without falling</th>
<th>Heel-side No. Of switches within lines without falling</th>
<th>Toe-side No. Of switches within lines without falling</th>
</tr>
</thead>
<tbody>
<tr>
<td>MINI 1</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>MINI 2</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>SnowGo 1</td>
<td>5</td>
<td>3</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>SnowGo 2</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>5</td>
</tr>
</tbody>
</table>
The results show that hypothesis 1 seems to be true. The subjects would also fall more often with MINI than with SnowGo during this exercise and would stand in their seat during the toe-side exercises in MINI to be able to ride toe side, which they did not have to do in SnowGo.

To verify hypothesis 2 the straight skidding test was done.

<table>
<thead>
<tr>
<th>Straight skidding</th>
<th>Heel-side Deviation from straight [cm]</th>
<th>Toe-side Deviation from straight [cm]</th>
<th>Heel-side Deviation from straight [cm]</th>
<th>Toe-side Deviation from straight [cm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subject 1</td>
<td>subject 1</td>
<td>subject 1</td>
<td>subject 2</td>
<td>subject 2</td>
</tr>
<tr>
<td>MINI 1</td>
<td>20</td>
<td>25</td>
<td>25</td>
<td>20</td>
</tr>
<tr>
<td>MINI 2</td>
<td>30</td>
<td>30</td>
<td>x</td>
<td>20</td>
</tr>
<tr>
<td>SnowGo 1</td>
<td>20</td>
<td>X</td>
<td>30</td>
<td>10</td>
</tr>
<tr>
<td>SnowGo 2</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>5</td>
</tr>
</tbody>
</table>

These results seem to show that hypothesis 2 is also true. It is not as evident as with former hypothesis but similar results can be see with MINI and SnowGo which also validates this hypothesis. The x’s resemble invalid data/results. In both cases the sit-snowboarders steered the board instead of skidding.

For the third hypothesis the steering a turn tests were done.

<table>
<thead>
<tr>
<th>Test no.</th>
<th>Heel-side</th>
<th>Toe-side</th>
<th>Heel-side</th>
<th>Toe-side</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>c</td>
<td>p</td>
<td>c</td>
<td>p</td>
</tr>
<tr>
<td>MINI 1</td>
<td>270</td>
<td>70</td>
<td>210</td>
<td>370</td>
</tr>
<tr>
<td>MINI 2</td>
<td>76</td>
<td>130</td>
<td>270</td>
<td>360</td>
</tr>
<tr>
<td>SnowGo 1</td>
<td>390</td>
<td>390</td>
<td>270</td>
<td>200</td>
</tr>
<tr>
<td>SnowGo 2</td>
<td>50</td>
<td>120</td>
<td>130</td>
<td>290</td>
</tr>
</tbody>
</table>

Figure 35.3 – Data collected on the turn initiation; A) Heel side turn, B) Toe side turn. The blue/thick data points are the data points collected with the use of SnowGo and the pink/thin data points are the data points collected with MINI. The venus symbol represents the female test subject, test person 1, and the mars symbol represents the male test subject, test person 2.

The results (Fig. 35.3) seem to show that there is more spread in the data gathered with SnowGo but that this data is in general closer to the red target pawn. This seems to
show that SnowGo performed similar or even better than MINI but further research should confirm this.

NOTE – No firm conclusions can be made from this data since the amount of test-subjects were insufficient. The implications done should therefore be verified with further research.

**Preliminary chairlift tests – Snowworld Landgraaf**

The chairlift snow-tests had a hypothesis which was:

1. The sit-snowboarder can maneuver a chairlift with SnowGo, without falling.

One test subject participated in this test; Male, 27 years old, 1.70 m tall, 80 kg, with cerebral palsy at L1 and 15 days of experience in sit-snowboarding. In indoor snowsport facility Snowworld Landgraaf there is one chairlift, this chairlift was maneuvered by the test subject. The test subject did 5 trials, 2 trials with help and 3 trials without. The test subject fell down after exiting the chairlift in his first trial. All the other trials were performed without falling, which seems to validate hypothesis 1. This has shown that the safety bar of the chairlift could close, this makes every ride safer and provides the sit-snowboarders with the possibility to lean forward.

NOTE – No firm conclusions can be made from this data since the amount of test-subjects and chairlifts used were insufficient. The implications done should therefore be verified with further research.

**References**


Appendix 36

Comments of Snowboarding test persons
This appendix summarizes the notes and things said during the breaks of the snowboarding tests in Snowworld Zoetermeer. On the disk at the back of this report the transcripts of the things that were said can be found. This appendix will close off with some side notes on the tests.

Notes and conclusion

Female test subject: Felt like she could not generate enough force with MINI's handlebars. She felt like MINI was supposed to be controlled with the handlebars since she could not lean into the positions as easily as with SnowGo. MINI’s rider position felt more like a sledding position whilst SnowGo felt more like a “real” snowboarding position and had a more active rider position. MINI generated a more comfortable sitting position and made her legs feel less tired. However if Celine wanted to sit comfortably in MINI she would not touch the knee pads. The female test subject felt like it would be less scary to fall over with MINI due to the lower sitting position.

Male test subject: The male test subject was generally very positive about SnowGo and felt less of a connection with MINI. This had mostly to do with the stiffness of the limiters. The sitting height of SnowGo also made the male test subject feel more comfortable since it allowed for an active yet comfortable sitting position and the knee pads of SnowGo fit better to his knees. The male test subject felt like he had more control and feeling with the snowboard on SnowGo since the handlebars allowed for easy transfer of torsional forces to the snowboard and the limiters allowed for easy force distribution in both heel- and toe-side motions. The male test subject felt like he was cheating in MINI since he would get up (using his upper legs) to put more weight on the toe-side.

Side notes

With Both the male and female test subject it was seen that they would try and stand up whilst using toe-side with MINI. This phenomenon was most clearly seen with the female test subject since her buttocks would not touch the seat during the toe-side snowboarding on MINI. It was interesting to hear that the female test subject felt like she was using her upper legs more with SnowGo, however video images do not show her standing in this prototype.

The lunch break should be in the middle of the test sessions, instead of exactly after two hours. The break should be seen as part of the test protocol. The test subjects mentioned that they did not perform as well right before the break because they were tired.
Appendix 37
SnowGo Chairlift Manual
In this appendix an instruction manual for using the chairlift with SnowGo can be found.

**Instruction manual for riding a chairlift with SnowGo**

The following instruction should be read carefully before trying to maneuver a chairlift with SnowGo. When loading and unloading a chairlift the sit-snowboarder should keep the following guidelines in mind.

**Loading a chairlift**

Before loading a chairlift the sit-snowboard should be brought from the snowboard mode into a chairlift mode (Fig. 37.1). To do so the sit-snowboarder or instructor should take out the two handlebars, after which the seat construction should be turned from the snowboarding to the chairlift mode. Now that the seat has been turned the sit-snowboarder should move his/her buttocks as far backward/into the seat as possible.

After doing this the sit-snowboarder or instructor can move the sit-snowboard towards the chairlift. Wait until the gates allow you to pass and move towards the load here sign. Wait here until the chairlift chair hits the snowboard, then lean back and grab the back of the chairlift chair. Wait until the sit-snowboard has cleared the snow and then lower the safety bar with one hand. Once the safety bar is closed the sit-snowboarder can let go of the backing of the chairlift chair.

During the chairlift riding phase the sit-snowboarder has four options as were to put the handlebars; 1) put the handlebars on the chairlift if the space allows to, 2) put the handlebars in between the knee pads and let them rest on the board, in this case hold them with one hand, 3) put one of the handlebars back into its standard in the sit-snowboard, and chose either option one or two for the other handlebar, 4) hold both of the handlebars. When choosing option 3) the sit-snowboarder or instructor should do this before moving towards the chairlift.

**Unloading a chairlift**

When approaching the top of the chairlift, hold onto the chairlift chair back with one hand and use the other hand to raise the safety bar. The sit-snowboarder should hold onto the chairlift chair until the sit-snowboard hits the snow. When the sit-snowboard hits the snow the sit-snowboarder should move his/her weight forward by either moving the upper body forward or by moving the knees into the knee pads and moving the upper body forward. This will help with clearing the sit-snowboard seat off of the chairlift chair. Once the seat is off of the chair the sit-snowboarder should use his/her hands to push themselves away from the chair. Using a hand to keep the sit-snowboard seat in front and off of the chairlift chair at a flat area and really push away from the chairlift once the chairlift gets at its turning point. At this point the slope is mostly in the sit-snowboarders favor (negative slope angle), and will help him/her get away from the chairlift.
Appendix 38
Discussion
In this appendix the full discussion of the results in this research can be found.

During the design and testing of this prototype certain possible design and testing improvements were noticed. A discussion of these improvements will follow.

**Design**

During the creation of this prototype some design decisions were made because of the limited amount of time and money available. With more time and money some design decisions would have been made differently. SnowGo is fairly heavy and even though no real weight problems were found during the snowboarding tests it is preferred to keep the weight to a minimum to be able to transport the prototype. In order to downgrade the weight, multiple things can be done;

1. The bearing used is made out of solid aluminum and should be changed to a lighter option like the Igus PRT-01-60, [38.1].
2. The limiter plate should be optimized according to its loading and need in size. No research has been done towards the actual spacing needed between the limiters and thus the limiter plate size, this can be done in order to optimize the design of both the limiters and the limiter plate. A honeycomb structure of the limiter plate could possibly bring down the weight of this plate (Fig. 38.1)[38.2].

![Honeycomb structure](image)

3. Research should be done towards the actual loading of the design, both the handlebars and sitting construction. The design can be altered accordingly, this would most likely downscale the tubing and thus the weight.
4. MINI’s tubing was made out of aluminum, due to time restrictions this choice was kept intact during SnowGo’s design. Further research into the actual loading of the tubing can be used to rethink this design choice. It is interesting to look into carbon fiber, or steel as an alternative to aluminum. The carbon fiber is very light weight but has the disadvantage of being relatively expensive. The steel is heavier but does create options for making the tubing less bulky which might result in less weight after all.
5. When the actual loading is known the feet straps can be made less complicated and less bulky, by downscaling the solid aluminum used. The adjustability of the feet straps should possibly be kept for convenience.

Apart from these improvements further improvements can be made to the actual design and implementation of the design.
1. When the sit-snowboard loads the chairlift it would be good to shift further back into the chairlift chair. This can be realized by translating the sit-snowboard seat backward or by making a notch in the vertical tube (Fig. 38.2). Each option has its advantages and disadvantages.

![Diagram](image)

Figure 38.2 – Shifting the sit-snowboarder further back into the chairlift chair; A) translating sit-snowboard seat, B) making a notch in the vertical tube

a. When creating a notch there will be space for the chairlift chair to move further under the sit-snowboard seat but this does mean that either the bearing has to be moved down or that the bearing will sit onto the chairlift chair. The first option means that the forces on the bearing will be higher and that means that the bearing will be more expensive, the latter option means that the sit-snowboard seat needs to be higher to clear even the highest chairlift chairs. Raising the sit-snowboard seat is disadvantage since this means that the sit-snowboarder will fall harder and more easily due to a higher COM. A higher COM also means that the sit-snowboarder will have a harder time getting up after a fall.

b. Making the sit-snowboard seat translate backward has the advantage that it stays at the same sitting-height. However making the sit-snowboard seat translate does mean that two bearings need to be attached to one another, the translating bearing and the rotating bearing. This combination of bearings will possibly cause difficulty in design.

2. The sit-snowboarders’ sitting height is important for the z-directional placement of the COM. A higher COM makes it easier to steer the board but if the COM is too high the sit-snowboarder cannot properly correct for any mistakes since any movement he/she will make will influence the snowboard motion too much. Sit-snowboarders mentioned that they feel more safe on a sit-snowboard that is lower since this makes them fall less hard. The trade off in this design decision is this; either the sit-snowboard seat is low and feels safe to fall with but cannot use the chairlift without a mechanism to raise it for the chairlift, or the chairlift can be used and the sit-snowboard seat is 50 mm higher than with MINI. SnowGo’s design could be lowered about 35 mm if the sit-snowboards seat would be placed onto the chairlift chair without anything in between. This might be interesting to look into, however the sit-snowboarders were not unanimous about the sitting height (App. 36). Further research should look into the desires of the sit-snowboarders regarding the sitting-height.

3. All though the locking mechanism of the handlebars works like it should and is created out of standardized parts that can be bought in any hardware store, the amount of parts and assembly time needed leaves much to be desired. For commercial use the insert of the locking mechanism should be redesigned for faster assembly times. The use of a brake cable should also be reconsidered, since
this might stretch during use and can eventually break. The reason the brake cable was chosen as a good option is that they can be bought in every snow shop due to the summer activities in most winter sport areas, it is also a cheap and replaceable part. A choice needs to be made between something that will break but is easy to replace and something that will hardly ever break but is hard to replace.

4. The materials used in the handlebar bearing could not be used on the inside of the lower attachment to the board (Fig. 38.3A), due to the shrink factor. However the placement of this bearing on the outside of the upper part (Fig. 38.3B) makes it vulnerable to damage.

![Bearing](image)

Figure 38.3 – attachment of the handlebar bearing; A) inside lower part of the handlebar, B) outside upper part of the handlebar

Using a different material for the bearing would be one option but most plastics which would be a good bearing material have even higher shrink factors meaning they would be even less appropriate. A better option might be to change the configuration of the lower part of the handlebar. However doing so would result in having to switch the working principle of the locking mechanism too.

5. In the plate of the locking pin of the seat of the sit-snowboard seat construction it can be seen that the stainless steel pin digs into the aluminum plate. A different material plate might be a better option here.

6. Getting into the sit-snowboard has been made quite difficult by the two tubes in between the legs. It should be investigated if this is an actual problem and how this can be solved if it is. Getting in and out of the sit-snowboard will probably only have to be done twice a day which makes this a minor problem, however if it has to be done more often it might be a problem that has to be dealt with.

7. The placement of the locking pin of the sit-snowboard seat should be analyzed with a sit-snowboarder group. It is now nicely integrated into the design and easy to reach but since it is in between the legs of the sit-snowboarder which might look odd when the sit-snowboarder tries to grab the pin.

There are also some options that this design creates which should be explored in further depth.

1. This prototype has two board modes; the snowboarding mode, and the chairlift mode. The chairlift mode is similar to a sit-ski position and can also be used to get down a slope. The opportunity lies in the fact that these two sports can be combined within SnowGo, this means that the sit-snowboarder could use the sit-snowboard to sit-snowboard with and to “sit-ski” with. The sit-snowboarder could then switch between the two sports as he/she prefers.
2. The handlebars can be used to propel the sit-snowboarder when he/she is in the chairlift mode. Even though this already worked on this prototype the handlebars in this prototype have not been specifically designed to do so, further design work should focus on making this work better. The integration of ski-crutches in this design would allow the sit-snowboarder to "sit-ski" when unloading the chairlift.

3. SnowGo can be adjusted to fit the lower leg of the sit-snowboarder. More research should be done in the adjustability of the sit snowboard incl the effect that has on the placement of the COM. The adjustability of the seat, knee pads and feet straps would be good to properly adjust the sit-snowboard to the sit-snowboarder. The fit of the sit-snowboarder in the sit-snowboard could possibly influence his/her abilities to maneuver the sit-snowboard. The adjustability of the handlebars should therefore also be researched.

The design of certain parts can be used in other fields:

1. The seat bearing and locking mechanism
   1.1. The swivel/rotational system of the sit-snowboard seat can be used to turn car seats. This would make it easier for people to get in and out of their car, especially elderly people and parents with kids could benefit from this function.
   1.2. The swivel/rotation system of the sit-snowboard seat can also be used to rotate the seat on electric wheelchairs, this is often done with different systems which seem difficult to reach for some user groups.
   1.3. When including the swivel/rotational system in a chair for children the system provides a safe and easy way to improve the interaction with other children and the rest of the world for children that have to be placed in stationary standing/sitting device for medical reasons. Without sacrificing safety and stability
   1.4. The method of rotating and locking the seat in various orientations can be used to give workers a sturdy support while working on different benches at the same time.

2. The handlebar bearing and locking mechanism
   2.1. The method of locking and releasing the handlebar can be used in various circumstances where the point of fixture is out of reach from the user. An application like this could be; providing a non-permanent support arm when getting in and out of a boat where a permanent support arm can cause problems when going under bridges

Testing
This section the side notes to the testing are discussed.

1. Handlebar and limiter tests:
   a. Friction in the pulleys influenced the outcome of the handlebar tests. The friction did not interfere with the result comparison. It can however not be concluded that this weight is the amount of force needed to steer the snowboard.
   b. The set up stands on a wooden board, the tilt of this board needs to be avoided and counter acted with counter weight. When the test-administrator takes the measurements he/she should remember not to stand on the wooden board to avoid influencing in measurements.
c. The handlebar and limiter have been done using weights which provides an objective result. The results can however not determine whether the sit-snowboarder will feel comfortable applying this amount of force or not.

2. Dry tests with subjects:
   a. The markers on the test subjects have to be attached properly to be able to use them, clothing is not a correct attachment because most of the clothing made the markers shift from their original position. During the snow tests the subjects were given a helmet and the marker was placed on this helmet, this should also be done with the dry tests with subjects to be able to compare these situations more carefully.
   b. It was hard for test subjects to fold forward with a straight back during the falling test and chairlift test. Subsequent tests would possibly benefit from some kind of harness to keep their spine from arching.
   c. Most people, 10 out of 12, used the table to turn themselves from the snowboarding mode to the chairlift mode. One should keep in mind that this is not always possible on a slope.

3. Snowboarding tests in snow:
   a. With straight skidding it is important that a straight piece of slope is chosen for this test. In this preliminary test the piece of slope was not completely straight. This time the next best thing was performed by keeping all the tests at the same spot, meaning the test subjects would break out at the same point every time.
   b. In subsequent research the turn initiation test should be done with the following task description; there is a line on the slope, this is the ideal line, try and stay as close to it as possible. This ideal line should then be created with some sort of color sand or spray. Changing this procedure possibly makes it easier for the test subjects to perform the task without falling. During this research the subjects would often tumble over at the target cone.

4. Chairlift tests in snow:
   a. The chairlift test performed was a preliminary test and should be expanded by using more test subjects and more and different kind of chairlifts.
   b. The option to shift the COM placement beyond the edge of the chair allows a sit-snowboarder to ‘fall’ out of a chairlift, which means that the sit-snowboarder is in control [38.5]. Even though the sit-snowboarder should not fall out of the chairlift during this ride this feature can be important during loading and unloading of the chairlift, since the sit-snowboarder can then determine when to get out.

Other things that this research showed can be important for different branches or fields of research:

1. This research seems to show that the feet are indeed not needed to steer the sit-snowboard. Current sit-snowboarders of the sit-snowboard all had some function in their legs, which mend it was never seen that the feet had not influence on the snowboard during sit-snowboarding.
2. The preliminary research done in this study has shown great value. The outcome of the questionnaire can be used in further design efforts for sit-snowboard, but also for sit-ski and other snow related products. It seems that this research could even be used in the design of other products for this user group.
Further research

Further research should be done to develop this prototype and gain more understanding in the forces on the prototype and working process of the prototype.

1. More research should be done to the mechanics and dynamics of the sit-snowboard and sit-snowboarding. The motions of the sit-snowboard should be studied and the influence of both the limiters and the handlebars in the forces on the snowboard should be analyzed. Researching the mechanics and dynamics possibly allows a design closer to the cutting edge of the design parameters.
2. More research should be done on the chairlift usage. Tests should be done with more people and more chairlifts.
3. The placement of the COM should be research to investigate what the neutral position of the sit-snowboarder should be on the snowboard. One option would be to investigate how much the sit-snowboarder can bend his/her back forward and how far backwards. After determining the comfort zone of these bending options is, a comfortable position can be determined. [38.6][38.7][38.8].

Reference

[38.1] Igus [Web page], [cited 2013, 12-2013], available from http://www.igus.nl/


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