DEVELOPMENT AND TESTING OF A PARAGLIDNG SYSTEM FOR PEOPLE WITH LOWER EXTREMITY DISABILITIES

by

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A thesis submitted to the faculty of
The University of Utah
in partial fulfillment of the requirements for the degree of

Master of Science

Department of Mechanical Engineering

The University of Utah

December 2012

The University of Utah Graduate School

STATEMENT OF THESIS APPROVAL

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ABSTRACT

The Phoenix flight chair was developed as an adaptive sport chair primarily as a paragliding system to facilitate tandem and independent flight for people with lower extremity disabilities such as spinal cord injuries, amputations, and neuromuscular disease. The Phoenix allows individuals with a wide range of disabilities and mobility to learn to paraglide. The main purpose of the Phoenix is to safely introduce individuals to the sport of paragliding and let them experience the freedom that flight brings. The development of the Phoenix was initiated by the not for profit organization, ABLE Pilot. A program developed to help individuals with lower extremity disabilities paraglide. An early ABLE Pilot publication stated that the effort "is a research and instructional program designed to establish and support the overall goal of developing and testing a formal paragliding and hang gliding instructional protocol for student pilots with various disabilities (e.g., spinal cord injuries, neurological and neuromuscular disabilities, amputations, etc.)."

Since the start of the project in early 2010 many milestones have been reached including two functional prototypes (Phoenix 1.0 and the Phoenix 1.5). Over 275 combined flights have been completed, including solo and tandem flights, with both able-bodied and disabled individuals. A training program and protocol is currently being developed by world class paragliding instructors. Five individuals have reached P-1

certifications, two of whom will have P-2 certifications in September 2012, and worldwide interest in the Phoenix has been a positive side effect.

One of the most important lessons learned through the Phoenix program is the difficult task of designing safety into the Phoenix. Even with the many safety features and precautions added to the chairs, unexpected events can happen. Although paragliding is a high risk sport, at no time should users be exposed to any avoidable risks. Existing chairs along with future chairs will continue to progress and safety modifications will be added to help reduce expected and unexpected dangers. For continued growth and regulation, the Phoenix is being adopted by the United States Hang Gliding and Paragliding Association (USHPA). The training program being developed by Mr. Rob Sporrer and Mr. Nick Greece will become the first official training protocol using the Phoenix system. This will provide individuals and instructors with the knowledge and experience they need to train and fly with the Phoenix.

The Phoenix program represents an enormous collection of thoughts and ideas. It would not have been successful without the volunteer students and pilots, ABLE Pilot, and University of Utah students and faculty. Continued improvements, more flights and additional design improvements are planned in the future.

To Michelle & Morgenn

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ACKNOWLEDGMENTS

I want to express my appreciation for the many individuals that have helped me to become who I am today. It would be impossible to thank everyone and because of that I will just give my thanks. I am thankful for the opportunity to have worked on this project and be a part of the lives of the few it has already touched. I am humbled at the opportunity I have had and will never forget the journey in getting to this point in my life. I have grown not only as an engineer but as an individual as well and I look forward to the challenge that the world has in store for me and will face it with excitement.

CHAPTER 1

INTRODUCTION/BACKGROUND

“The great bird will take flight above the ridge…filling the universe with awe, filling all writings with its fame…” (USHPA, 2012) Humanity has always been fascinated by the prospect of flying. From Da Vinci’s many sketches, to the Wright Brothers, to the various forms of powered flight, hang gliders and many other types of human flight, man has always desired to take to the skies.

1.1 General Paragliding Information

Paragliding is a relatively new flying sport. The first recorded attempt was in the mid-1960’s when an enthusiast named David Barish began paragliding using skydiving parachutes and a steep mountain to glide to the bottom of a high hill (USHPA, 2012). The sport as we know it today was not fully developed until 1978 in Mieussy, France. Its popularity grew rapidly as commercial manufacturers from France and Switzerland continued refining the flight of paragliding. (USHPA, 2012). Enthusiasts have chosen this sport all over the world, and even in Utah, one can see paragliders flying daily on either the north or south sides of the Point of the Mountain, Utah, at the border of Salt Lake and Utah counties.

As with many other sports, people with physical disabilities find it difficult to participate in paragliding using the traditional equipment. To facilitate the participation of these individuals, the Phoenix project was born.

1.2 Paragliding for Persons with Disabilities

The Phoenix is an adaptive sport chair that allows paragliding flight for individuals with lower extremity disabilities. The development of the Phoenix was initiated by the ABLE Pilot program. An early ABLE Pilot publication stated that the effort “is a research and instructional program designed to establish and support the overall goal of developing and testing a formal paragliding and hang gliding instructional protocol for student pilots with various disabilities (e.g., spinal cord injuries, neurological and neuromuscular disabilities, amputations, etc.)” (Gaskill, 2012).

Numerous training programs exist that allow able bodied pilot-instructors all over the world to train and certify students. This training is important for the safety of the pilot, students, and those around them. At the time the ABLE Pilot program was conceived, an established paragliding pilot training program was not available for individuals with spinal cord injuries or other conditions limiting the control of the torso and lower extremities. Since this population generally has decreased sensation, it is extremely important that the paragliding system and training protocol not increase the risk of injuries, such as broken bones, that might go unrecognized.

In January 2010 multiple chair prototypes of various shapes and sizes existed around the world, none, however, met the needs for the training and safety of these unique individuals. The Phoenix system was created to help address these issues.

CHAPTER 2

DESIGN/DEVELOPMENT OF PHOENIX 1.0

2.1 Contact with ABLE Pilot

In January 2010, ABLE Pilot personnel (see Appendix B) realized additional support for the Phoenix system would be needed and sought out the direction and guidance of Dr. Donald Bloswick, Professor of Mechanical Engineering at the University of Utah. Under Dr. Bloswick's direction, a team of four mechanical engineering seniors, Bryon Densley, Christopher Graves, Benjamin Davidson, and Travis Smith (see Appendix A), was established in February 2010 to build and test the first system, the Phoenix 1.0. The initial goal was for the Phoenix 1.0 to fly safely at the Utah AAA Sprints competition held on May 27 through 30, 2010 at the Utah State Flight Park at the Point of the Mountain, Utah.

Soon after the initiation of the project the team came to the realization that there was considerable work to be done and that there were almost limitless possibilities for those with disabilities. In addition to the development of paragliding equipment, the team facilitated the extension of the paragliding sport to a new population. This included the development of protocols and instructional programs with the express goal of providing individuals with disabilities the ability to learn to paraglide and participate in this exhilarating sport.

2.2 Previous Designs

To determine the state of the art and set a baseline for system development, multiple designs from existing chairs around the world were reviewed. This review involved an evaluation of the pros and cons of each design. To determine if certain features were a pro or a con the team referred to a list of performance specifications, discussed further in section 2.3. Three primary sport chairs for persons with disabilities were evaluated. These examples are shown in Figures 1, 2 and 3.

Figure 1: Existing Example #1 (Greece, 2012)

Figure 2: Existing Example #2 (Greece, 2012)

Figure 3: Existing Example #3 (Cannalonga, 2012)

Figures 1 and 2 illustrate examples used currently in the sport of paragliding. Figure 3 is an example of a downhill mountain racing chair. The rationale for reviewing these designs was to accommodate certain features that would have been benefit in the design of the Phoenix 1.0.

Some common features among the previous examples were excessive weight, lack of protection for the passenger, unstable wheel configuration, makeshift steering setups, and awkward seating arrangements. Some chairs (not illustrated above) had a four-wheel configuration that gave the appearance of a child's buggy and was not desirable.

2.3 Performance Specifications

In February 2010, when the project was in its infant stage the team was given a short list of initial performance based requirements to assist in determining the design of the Phoenix 1.0. These parameters included:

- Overall lightweight
- Durability
- Provide shock absorption upon landing
- Provide a means to brake when on the ground
- Allow both tandem and solo flights
- Allow ground transport of the pilot and/or passenger with disabilities
- Allow launching and landing on rough terrain in a variety of wind conditions
- Allow the user to fly with only upper body movement
- Allow the user to load/unload the system from a vehicle
- Present minimum difficulty in getting in and out of the seat and harness

2.3.1 Mechanical Performance Specifications

The Phoenix system is made up of five primary components; frame, wheels, harness, wing structure, and the human (pilot and student). Failure of any component can cause the entire system to fail or cause injury to the pilot. During development, the team had to understand the interactions of the mechanical and performance characteristics of each component and how this interaction relates to overall system safety and performance.

The frame needed to accommodate both a student and a pilot-trainer to facilitate tandem flight until the student reached the correct certification. The frame needed to withstand a possible roll or high ground impact and protect the student within the confinement of the chair.

To assist ground transport from a vehicle to a launch site, as well as provide rugged tread for landing, the team decided to use 26" Mavic Crossride UB front mountain bike wheels (~780 grams) with Panaracer Fire XC Pro tires (~580 grams) for the rear and 20" Alex Y22 BMX wheels (~475 grams) with Cheng Shin Comp III tires (~300 grams) for the front. This combination allowed maximum ground clearance and facilitated ingress/egress for the person sitting in the chair. These wheels/tires were also more than sufficient to handle rugged and solid landing surfaces on terrain that could vary from grassy parks to rocky mountain landscapes. After looking at the risks of a three-wheel design (see Figures 1 and 2), the team decided on a four-wheel design (similar to that in Figure 3) giving the greatest level of stability upon landing for a beginning student. Unlike previous examples, the team decided against a steerable front wheel. The risk of a mishap caused by a wheel shifting or rotating upon landing was too great and overshadowed the benefit. The only real benefit that the team could see with a steerable front wheel was the ease of transporting the Phoenix system to the launch site. Because of this, the final decision was a fixed wheel configuration. Figures 4 and 5 illustrate that in previous designs both front wheels have been secured to stop any rotation.

Along with the four-wheel design, shocks were added to each wheel. The resulting independent suspension allows for separate adjustment to the front or back suspension, depending on the passenger's needs, along with the ability to dampen harsh landings or jarring on launches and landings. 3D model representations and Phoenix 1.0 images can be found in Appendices H and I. These images were taken during the maiden flight of the Phoenix 1.0.

Along with designing and building the frame of the Phoenix system, a custom harness was required in order to achieve the highest level of maneuverability. A normal paragliding harness is set up for maximum control and comfort while maintaining the correct center of gravity. The harness of the Phoenix system required connection points to hang the chair, as well the ability to adjust the center of gravity based on the needs of the student.

Since the team had no specialization in this type of work, Bill Belcourt of Black Diamond, Inc., an expert in the design and modification of paragliding harnesses, volunteered to assist. The finished harness can be seen in Figure 6 along with the Phoenix 1.0.

As with all gliding or flying machines, the wing is what makes flight possible. The Phoenix system uses a typical paragliding wing available from various manufacturers.

Figure 4: Example #1 Front Wheel Configuration (Greece, 2012)

Figure 5: Example #2 Front Wheel Configuration (Greece, 2012)

Figure 6: Phoenix 1.0 Along With Harness (Densley, 2011)

The size and characteristics of the wing are determined by the program test pilots. Wings built for tandem flights were selected to support the extra weight of the chair and passenger.

No flight would be possible without the pilot. In the case of the Phoenix system, this includes both the pilot-trainer and the student. The skills of the instructor are critical to the success of the Phoenix system. The training, practice and certifications of the pilot-trainer help provide the utmost level of safety in this high risk sport for the student. Because of this, a training protocol is being developed by Nick Greece and Rob Sporrer, both world ranked paragliding pilots.

The weight of the assembled system was critical and the weight of every component was reduced as much as possible. Maneuverability and wing design is directly related to the weight of the pilot and his equipment. The chair had to be overall lightweight, but also durable enough to take repeated use and impacts upon landing.

In order to minimize risk, a failure modes and effects analysis (FMEA) was completed and risks evaluated. See Appendix L. The risk assessment matrix in Appendix M was used to rank each potential issue. It was imperative for all high risks in zone 1 to be corrected and risks in zone 2 to be assessed and determined if action was needed. The analysis revealed no imminent dangers that would require attention. There were a few occasions of risks with a high severity but the event probabilities were negligible. The highest concern to the team was to maximize safety on landing. Landings proved to be the highest risk due to increased probability and the highest severity. Stability issues upon landing were common in the early testing stages and minimized with operator training. Increased stability will be added to future chairs to increase safety and mitigate risk.

2.3.2 User-Defined Performance Specifications

For the safety and comfort of the pilot and passenger it is important that the design of the Phoenix facilitate easy ingress/egress from the system. This reduces the stresses involved with getting into and out of the chair.

The Phoenix system also had to be balanced while in the air. If the Phoenix system were to launch while unbalanced the chair might go into a “nose-up” position impairing the visibility of the pilot or passenger in the chair, which, along with modified flight characteristics, would be a safety concern. The harness was designed so that the center of gravity can be altered, and multiple connection points on the frame provided even more adjustment. This allows the trainers to accommodate the different weights of pilots when flying solo or the combined weight of the pilot and passenger.

2.4 Phoenix 1.0 Design Based on Performance Specifications

One of the critical design parameters established for the Phoenix 1.0 system was an overall lightweight design. Because the wing is designed to support a specific weight range, if the weight is above or below that for which the wing is designed, the characteristics of flight will change and safety could be impacted. A heavy chair would be less nimble in the air and more accident-prone because of that decreased maneuverability. In addition, a heavy chair would be more difficult to handle on the ground and to load into a vehicle, causing undue strains and stresses on attending personnel. 3D generated models can be found in Appendix H of the electronic design. These models were built prior to manufacturing.

The world-class design of the Phoenix system along with a custom harness from Bill Belecourt, as mentioned previously, has given the Phoenix systems unparalleled maneuverability while in flight. Pilots have reported that this maneuverability is essentially equal to that of a typical paragliding harness, which increases safety due to the familiarity for the pilot while in the air. As expected, launching and landing the Phoenix is significantly different than that of an able-bodied launching/landing. This has been the primary focus for the trainers, Mr. Sporrer and Mr. Greece, and is being developed over time. It has also been the source of multiple modifications due to lessons learned while in the field. A completed version of the Phoenix 1.0 can be seen in Figure 7.

After investigating commercially available powered paraglider frames, the team decided that one inch outer diameter tubing would be used for the frame of the

Figure 7: Phoenix 1.0 in Sun Valley, Idaho (Densley, 2012)

Phoenix 1.0. The team discussed the pros and cons of two different frame materials. One possibility, an alloy of chromium and molybdenum, would be heavier, but stronger. This common alloy is used in aircraft frame manufacturing and is called chrome-moly 4130. The second choice would be 6061-T6 aluminum alloy, which would be lighter than, but not as strong as the chrome-moly 4130. Since the frame was not expected to experience consistent high impacts, the team chose to use 6061-T6 aluminum alloy for the initial design because it had sufficient strength for the frame as well as a lower overall weight. Chrome-moly 4130 steel was selected for the swing arms because these components would be subjected to the highest forces on a consistent basis. Although use of steel in the swing arms added additional weight, it would also be better suited for the impacts associated with landing on rough terrain or the impacts from an emergency landing.

In order to determine the tube wall thickness the team calculated $F_{allowable}$, $M_{allowable}$, and the weight per foot. These two sizes were recommended by the vendor responsible for bending and welding of the frame. Based on these calculations (see Table 1) the team decided to use a wall thickness of 0.083" for the increased strength even with the increased weight. The percentage difference for each of the calculated properties can be seen in Table 2. Detailed calculations can be found in Appendix C.

2.5 Testing at the Point of the Mountain, Utah

On Saturday May 29th, 2010 at the North Side of Point of the Mountain, Utah, Brad Gunnuscio became the first to fly the Phoenix 1.0. The KSL report can be found in Appendix D. ABLE Pilot and the University of Utah personnel were extremely happy with the team's accomplishments and success with the Phoenix 1.0 and its design. Mr. Gunnuscio can be seen in Figure 8, just before the first launch of the Phoenix 1.0. Mr. Gunnuscio further tested the Phoenix 1.0 by executing a series of acrobatic maneuvers

Table 1: Calculated Properties for Considered Wall Thicknesses

Wall Thickness	$F_{allowable}$	$M_{allowable}$	lb per ft
0.083"	9.564×10^3 lbf	2.027×10^3 in·lbf	0.27976
0.065"	7.637×10^3 lbf	1.677×10^3 in·lbf	0.22339

Table 2: Percentage Difference

	% Difference
Mass	22.41%
$F_{allowable}$	22.41%
$M_{allowable}$	18.9%

Figure 8: Brad Gunnuscio Preparing for the First Phoenix 1.0 Flight (Densley, 2011)

which it performed flawlessly. Mr. Gunnuscio later mentioned to the team that he felt comfortable performing these maneuvers because the Phoenix 1.0 was performing so well and with such unexpected maneuverability. This was a major initial success for ABLE Pilot and the University of Utah team. Since the initial flight there have been numerous flights of the Phoenix and the subsequent design by both able-bodied and paralyzed individuals in both tandem (see Figure 9) and solo flight configurations.

Figure 9: Tandem Flight (Includes Passenger) (Smith, 2011)

2.5.1 User Experiences

Every pilot and passenger that has flown in the Phoenix 1.0 or the subsequent design has landed smiling and excited about their experience as seen in Figure 9. This in part has to deal with the exhilarating sport of paragliding along with the comfort produced by the Phoenix flight systems and many ask for ways to get their loved ones in the air.

2.5.2 Desired Mechanical Modifications

While the Phoenix 1.0 was successful with respect to maneuverability and comfort, there were a few things that had to be corrected. The system's center of gravity was not being adjusted for the pilot and passenger on each flight. This would sometimes cause a balance issue when the center of gravity would tilt the chair forward or backward. The effects of this unbalanced center of gravity caused decreased visibility and sometimes made passengers feel that they might fall out of the chair.

The headrest of the Phoenix 1.0 was insufficient in design. While designed to only be a headrest it was often used as a handle to push/pull people up large inclines and once broke during testing on the mountain. It was determined that the headrest would need to be modified to increase the strength and deal with the forces applied while pushing/pulling the Phoenix system. A redesign was also needed to improve occupant protection in case of a rollover. An example of this headrest can be seen in Figure 10.

The width of the second chair was reduced to allow transport in a larger variety of vehicles, and not be restricted to large SUVs, trucks and trailers. It was expected that this would also facilitate entry into buildings for shows and displays.

Figure 10: Headrest (Densley, 2011)

CHAPTER 3

DESIGN/DEVELOPMENT OF PHOENIX 1.5

3.1 Performance Specifications

The performance specifications for the second system, the redesigned Phoenix 1.5, were very similar to the Phoenix 1.0. The same goals still applied including special attention to weight, strength, and ease of manufacturing. The overall design also remained the same with a few small improvements that are discussed in sections 3.1.1 and 3.1.2.

3.1.1 Mechanical Performance Specifications

The biggest change with the Phoenix 1.5 was the change in the system's frame. Changing the frame to chrome-moly 4130 steel allowed a reduction in the wall thickness to minimize the increase in weight. Additional weight reduction was attempted in the Phoenix 1.5 but was not realized due to the additional connectors that had to be added for the harness. These connections being made out of chrome-moly 4130 increased the strength and the weight of the Phoenix 1.5 over the aluminum used in the Phoenix 1.0.

Other minor changes were made to both the Phoenix 1.5 and the Phoenix 1.0 for the second stage of training at Sun Valley Idaho. These included changing the foot constraints, the use of quick release wheels, and the incorporation of a removable head rest. The foot constraints were modified to use snowboard bindings for further adjustment and better constraint. See sections 3.1.2 and 5.2.1 for additional information on bindings.

With the use of mountain bike wheels/tires it was determined after the Sun Valley training that the aggressive tread was not required. In exchange for the mountain bike wheels/tires a removable setup with components from Ti-Lite, Inc. of Seattle, Washington was used. An additional benefit of removable wheels increases the ability to transport the Phoenix system.

The frame of the Phoenix 1.5 was simplified to reduce the number of welds during manufacturing. This was accomplished by using additional bends to mimic the design of the Phoenix 1.0 frame. These controlled bends improved the tolerances of the frame, reduced manufacturing costs and time, and increased the strength by reducing the number of welds in the system. Additional modifications to achieve a higher efficiency design for manufacturing in future chairs already exists.

The process mentioned above was used to create the removable head rests reducing the number of welds and increasing the number of controlled bends. Both Phoenix chairs were modified and equipped with removable head rests.

3.1.2 User-Defined Performance Specifications

One of the major achievements and distinguishing characteristics of the Phoenix 1.5 is its extraordinary maneuverability, as with the previous design. Many pilots state that once in the air the Phoenix 1.5 feels very much like a normal paraglider, and the pilot is able to control and handle the wing as they would if flying solo in a “normal’ paraglider.

Due to the complexity of launching and landing it is important all procedures are being followed. This can be done through the use of ground personnel to assure that the wing is in position and to assist with pushing during launching. With all of these items happening at once the utilization of the brake lever became difficult. The lever was in the way both while on the ground and in the air, and was hard to find and use while landing and simultaneously using the wing controls. Upon landing the wing serves a similar, more effective, purpose of slowing the chair down. The primary function of the brake is to hold the system stationary while sitting on the ground and the wing is not inflated. Because of this, Mr. Greece requested that the brakes be removed altogether from the system. In response to this, a brake similar to that found on a wheel chair will be added to the system and engaged like a parking brake.

A reoccurring issue dealt with effectiveness of the foot restraints. The restraints were difficult to get in and out of and did not consistently keep the passengers legs and feet in place during flight. In order to abate this issue, snowboard bindings were installed. These bindings secured the feet and added the required support to keep the passengers legs from moving around.

3.2 Phoenix 1.5 Design Based on Performance Specifications

The most common suggestion from the participants in Sun Valley was moving to a three-wheel configuration with a front wheel that could swivel. The opinion of the design team, however, was that the Phoenix system as it stands currently is a training chair and must be extremely stable on launches and landings. The team decided that a three-wheel version would not be sufficient and that, for the immediate future, chairs would be a four-wheel design, similar to the Phoenix 1.0 and Phoenix 1.5. A three-wheel design was not ruled out for a more expert level or competition chair in order to decrease weight and improve aerodynamics.

3.3 Testing at Sun Valley, Idaho

The first flight for the Phoenix 1.5 was in Sun Valley, Idaho in August 2011. During these few days, ABLE Pilot arranged for five members of the Paralyzed Veterans of America (PVA) to be trained by Mr. Sporrer and Mr. Greece. These individuals consisted of Ernie Butler and Brent King from Washington State, Darol Kubacz from Arizona, Anthony Radetic from Georgia, and Erik Burmeister from Virginia. More detailed profiles can be found in Appendix G. As briefly mentioned earlier, both Mr. Sporrer and Mr. Greece are responsible for developing the training protocol for the Phoenix system due to their fantastic background in the sport of paragliding.

As found on the website of Eagle Paragliding, "Rob Sporrer has been flying paragliders since 1995, and teaching since 1998. Rob holds an Advanced Paragliding Rating, Advanced Instructor Rating, Tandem Instructor Rating, and is both a Tandem Administrator and Instructor Administrator. Rob was awarded the United States 2002 Instructor of the Year Award from the United States Hang Gliding & Paragliding Association (USHPA). Rob is also a certified EMT, and a member of the Sheriff Department's Santa Barbara County Search and Rescue Team. Rob teaches all over the world, and has been coaching The National Paragliding team at the world champions since 2009" (Eagle Paragliding, 2012).

Mr. Greece placed 3rd in the US Championships in 2009, 2nd in the Chelan Paragliding World Cup, Paragliding World Cup America's Cup, and US Championships in 2010 and in 2011 placed 7th in the Colombia Paragliding World Cup and 1st in the Paragliding World Cup America's Cup. Not to mention numerous trips for humanitarian efforts and a record breaking the 200-mile mark during a single flight in 2012 (OZONE, 2012).

Sun Valley training developed by Mr. Sporrer and Mr. Greece consisted of classroom lectures and hands on experience. At the end of the classroom lectures students had to pass an official USHPA exam. This test had to be modified slightly from the USHPA exam since the exams were originally directed at able-bodied pilots. The instructors modified the exams to reflect the capabilities of the students with disabilities and the characteristics of the Phoenix systems. Along with the written portion, all students were required to pass a tandem flight exam. By the end of the three day training camp all five veterans had earned their P-1 pilots license and the first in the world to be trained and certified by USHPA instructors using the Phoenix system. Having a P-1 license is the first of five steps to becoming a master pilot. See Table 3 for a list of USHPA ratings (USHPA, 2012). USHPA's certification and rating program goes hand in hand with a pilot's experience and training. For example, a P-1 beginner pilot (1) has the knowledge and basic skills necessary to fly and practice under direct instructor supervision and within significant operating limitations, and (2) understands the USHPA paragliding rating systems and recommended operating limitations. For more detailed requirements see Appendix J (USHPA, 2012).

The Sun Valley PVA training camp provided the largest amount of feedback to date for the Phoenix project. The information obtained was invaluable and was gathered through discussions with the pilot-trainers, students, and observations of the chairs in action. One very important discovery was that during training, the Phoenix should only be launched in limited climate and terrain situations and, for safety reasons, limits should

Table 3: USHPA Ratings

Code	Name	Rating Class	Rating or Skill
360	360° Turns	Solo	Special Skill
AWCL	Assisted Windy Cliff	Solo	Special Skill
CL	Cliff Launch	Solo	Special Skill
FL	Foot Launch	Solo	Special Skill
FSL	Flat Slope Launch	Solo	Special Skill
HA	High Altitude Launch	Solo	Special Skill
P-0	Student	Solo	Rating
P-1	Beginner	Solo	Rating
P-2	Novice	Solo	Rating
P-3	Intermediate	Solo	Rating
P-4	Advanced	Solo	Rating
P-5	Master	Solo	Rating
PS	Para-Ski	Solo	Special Skill
RLF	Restricted Landing Field	Solo	Special Skill
RS	Ridge Soaring	Solo	Special Skill
ST	Surface Tow	Solo	Special Skill
T-1	Tandem 1	Tandem	Rating
T-2	Tandem 2	Tandem	Rating
TFL	Tandem Foot Launch	Tandem	Special Skill
TST	Tandem Surface Tow	Tandem	Special Skill
TUR	Turbulence	Solo	Special Skill
X-C	Cross Country	Solo	Special Skill

not be pushed. This precludes launch in rocky terrain, steep launching sites and wind conditions that may be too light or heavy. Specific parameters for these limits are still being determined. Rough terrain was a constant issue for the instructors and they decided that future camps for beginning students would not use the Sun Valley training location since it is rated for P-3 pilots. During the Sun Valley camp a launch was attempted in rough down-hill terrain that resulted in a rollover. Fortunately, this did not result in injury to the pilot, student or observers. Overall, Sun Valley was a huge success for the Phoenix program from a design and awareness standpoint. It also gave the Phoenix exposure and generated interest and excitement of those involved in paragliding. The Phoenix system was featured in the Salt Lake City KSL newspaper in 2010 (see Appendix D), the University of Utah and New York Times in 2011 (see Appendix E and F), on local television newscasts in Salt Lake City, Utah in May 2010 and Santa Barbara, California in September 2012.

3.4 Testing at Santa Barbara, California

Due to the success and overwhelming interest of the Sun Valley training, two students were invited to a second training camp held in Santa Barbara, California in April 2012. The Santa Barbara location allowed training to be completed on less aggressive terrain. It was also observed that the increased air density at sea-level is much more forgiving when training and working with the Phoenix.

The goal of the training at Santa Barbara was to extend the basic knowledge gained by the P-1 pilots in Sun Valley. Starting in August 2012, Ernie Butler and Darol Kubacz, attended training in Santa Barbara which included ground school, solo launches, flights and landings. During this stage of training both students also completed solo high altitude flights. The high altitude flight was done in San Bernardino due to the ideal conditions as well as excellent conditions for launching and landing.

Both students, Ernie Butler and Darol Kubacz, continue to take flights in Santa Barbara with the expectation of completing the requirements for the P-2 certification. As a Novice Paragliding Rating P-2 pilot must display the knowledge and basic skills necessary to fly and practice without the direct instructor supervision but within significant operating limitations. The P-2 pilot also understands the USHPA paragliding rating systems and recommended operating limitations. For more detailed requirements see Appendix K (USHPA, 2012).

It was also determined in Santa Barbara that having an individual participate in paragliding with zero assistance from those around was not feasible. The complex nature of the sport can even be cumbersome to an able-bodied individual. Pilots and students using the Phoenix system will require assistance whether it is in loading or unloading from a transport vehicle or getting the wing set up for launch.

CHAPTER 4

LONG TERM TESTING OF PHOENIX 1.0 AND 1.5

4.1 Performance Specifications Reviewed

It was important for the team to compare the performance of the Phoenix 1.0 and 1.5 against the initial requirements provided. Original specifications found in section 2.3 included parameters based on weight, durability, ground use, and launch/landing performance.

The weight of the system was an important metric for the team and the instructors. The chairs have been successful to this point, however the team feels the weight of the chairs should be reduced even further. The weights of the Phoenix 1.0 and 1.5 are approximately 54 and 71 pounds, respectively. A reserve parachute will increase these number by approximately 10 pounds.

Feedback from students at the PVA training in Sun Valley, Idaho indicated that the width of the frame was too wide and to allow for better ingress/egress the frame needed to be narrowed. It was initially thought that 26” inside the frame would be required to allow for the passenger and sufficient padding. The largest attendee in Sun Valley was Anthony Radetic whose wheelchair had only 15” allowance for his seat cushion. The suggested frame width for the Phoenix 2.0 is 15” plus 2” of padding on each side resulting in a 19” inside frame-to-frame dimension.

4.2 Shock Behavior

The shocks used on the Phoenix are a critical component of the system, and the following details have been provided to help ensure their life and performance. The Phoenix system includes four 2010 Float R rear shocks by FOX (FOX, 2012), one for each wheel/swing arm combination to allow a full range of customizations and damping for different individuals and site locations. The shock allows for pressures from 50 psi to 300 psi (FOX, 2012). It is important to follow the guidelines that FOX has provided. These guidelines include: installation, maintenance, initial setup and adjustments (FOX, 2012).

FOX also provides service intervals for the Float R shocks. It is recommended that these service intervals be followed to help ensure the integrity and life of the system (FOX, 2012).

- New shocks
    - Set sag and damping adjustments
- After every ride
    - Clean shock and shock body (do not use degreasers)
- Every 30 hours
    - Clean and inspect bushing and reducers
- Every 100 hours or annually
    - Suspension fluid service by an authorized service center

In collaboration with FOX, the actual maintenance intervals may be modified if it is determined that the chair is not subjected to those same conditions as it might if attached to a mountain bike. These shocks are designed to act as a rear shock with approximately

250 pounds of person and equipment. The actual weight seen by each shock will be considerably less than this; however, since the system weight is distributed among the four shocks on the system. At this time a maintenance schedule and component replacement schedule has not been determined and should be analyzed with future versions of the Phoenix system.

FOX has also provided a list of common issues for bike suspensions along with solutions and tips in correcting these issues. These will provide the instructional team the information required to setup and adjust for a majority of conditions and issues encountered. For more detailed requirements see Appendix N (FOX, 2012).

4.3 Final Inspection

After hundreds of flights the chairs were inspected for issues that should be corrected when designing the Phoenix 2.0. A comparison of the preflight and existing frame could not be done due to the lack of initial measurements after the frame was manufactured. A comparison to the actual solid models was inappropriate since the manufacturing process of the Phoenix 1.0 and 1.5 may have deviated somewhat from the initial specifications. It is suggested that all future chairs be measured and documented immediately after manufacturing for comparison at a later time. The inspection of the Phoenix 1.5 frame and swing arms was very positive and showed minimal areas of wear and stress. The Phoenix 1.5 was disassembled and inspected part by part. Overall there were marks of use and wear in the powder coat that would have resulted in some form of impact or marks from strapping the chair for transport. The frame showed no cracking or signs of stress at weld locations other than the initial issue of the headrest being broken off (as discussed earlier). There were some signs scrapes and bangs on the swing arms, however, all appeared to be due to transportation. The largest concern with the condition of the Phoenix 1.5 was the quick-release axles. The quick-release axles were bent, see Figure 11. Upon further inspection of the swing arm and axle sleeves, no further detectable damage was found. It is proposed that landing forces be monitored for future versions of the Phoenix system. This can be done with the proper testing equipment attached to critical locations of the frame and swing arm. Tests may include actual landings or through a series of drop tests with the appropriate weight added.

Overall the team is pleased with these results and how well the Phoenix 1.5 has held up to the testing and training use to date. These results are not perfect, however, and, as will be discussed later, there is room for improvement with the Phoenix 2.0.

4.4 Testing Locations

The Phoenix program has had access to several world-class locations used for testing, ground school and training. These locations include the Point of the Mountain, Utah; Sun Valley, Idaho; and Santa Barbara (and San Bernardino), California. USHPA has established the rating system so that individuals are aware of the skill level required at

Figure 11: Bent Swing Arm of the Phoenix 1.5 (Densley, 2011)

each location. This system allows those properly trained to launch and fly safely from a particular location.

The Point of the Mountain, Utah is an excellent P-2 site that will allow for beginner low altitude practice launches along with more advanced high altitude flights. It will also serve as an excellent testing location for the Phoenix system due to its proximity to the University of Utah.

At this point in time, no further training will be done at the Sun Valley location. This is due to the potential risks to pilot and passengers at Sun Valley as a P-3 site and gusty wind and rugged mountain terrain.

The team was fortunate to work with Mr. Sporrer, world champion paraglider pilot and owner of Eagle Paragliding. Eagle Paragliding has a premier location in Santa Barbara, California. This location offers an excellent beginning training site. The increased air density and meteo (prevailing) winds offer increased safety over the mountain winds of Sun Valley which can be gusty and more thermal.

4.4.1 User Experiences

The development of the Phoenix system did not focus on the emotional state of individuals. However, the Phoenix system appears to have had an effect, and throughout all the camps and individual flights that the chairs have taken, this program has affected the lives of all those involved. Although, no research has been done at this point in time on the subject, the paragliding experience seems to have changed the morale of not only the passengers and pilots but for the families of these individuals.

4.4.2 Desired Mechanical Changes

One mechanical change required for the next iteration of the Phoenix system (Phoenix 2.0) is increased cushion design to increase individual comfort. This may involve the use of custom pads often used in individual wheel chairs or a custom cushion design performed by an outside source such as Supracor. As of September 2012 the team has been working with Supracor and Darol Kubacz to improve the comfort of passengers for the Phoenix 2.0. Additional improvements can be found in section 5.2.1 in General Parameters for the Phoenix 2.0.

4.4.3 Desired Training Protocol Changes

While training in Santa Barbara the training team found it to be beneficial for the students to train with able-bodied paragliding students. This allowed the students to watch and learn from the mistakes and successes of the others as well as normalizing the training with already developed procedures. Since Sun Valley, it has been noted that it is important for each individual to have his/her own chair during training. This minimizes transferring while training and increased comfort for the user. It also allows for shorter flights and a quicker turnaround time and more experience.

Future sites will be evaluated and characteristics similar to Santa Barbara will be considered for beginner trainings. These sites will be primarily grass along with smooth and gradual hills. Easy vehicle access to the launch site is also an important feature to assist in multiple and quick launches.

CHAPTER 5

FUTURE WORK

5.1 Phoenix 2.0 Proposed Design and Performance Specifications

It is projected that as corporate sponsors become involved and resources increase, the system design will continue to improve. For example, Supracor is a company that has volunteered their time to help create a state-of-the-art seating system for the Phoenix system. It is projected that donations from many other companies such as FOX Shocks, Black Diamond, Mountain Khakis, Kavu, and possibly Red Bull will help to realize the full benefits of this project.

Competition versions of the Phoenix are being discussed to allow users to take their paragliding training and competence to the highest level. This extension of the Phoenix program would offer advanced training programs and pave the way for chair designs with slimmer profiles possibly constructed from advanced materials such as carbon fiber or titanium.

5.2 Training Protocol

Just as the design and creation of the Phoenix has been a work in progress, so too has the training protocol. While not yet complete, the protocol will continue to be developed as the team meets in 2012/13.

The protocol is being developed primarily by Mr. Sporrer and Mr. Greece and consists of the following:

- Introduction of the team
- In-class instruction
  - Meteorological forecasts, winds, etc.
  - Gear
- History of the sport
- Getting ready to launch
- Hands on training
- Field training
- Flight training

5.2.1 General Parameters

The Phoenix 2.0 is expected to be the highlight of the Phoenix program. The design of the Phoenix 2.0 will be based on two years of experience in both design and flight. The Phoenix program is more than an idea on paper – it involves the design, evaluation, and redesign of functioning prototypes under varied terrain and flight conditions.

The Phoenix 2.0 continues to have the support of world-class pilots, and individuals dedicated to the development and success of the Phoenix and what it stands for. Some features and ideas for the Phoenix 2.0 include:

- Increased safety. It is a continuous concern for the team involved to increase safety and help ensure the future of this project. In order to do this a roll cage will be designed to provide increased occupant protection in case of a rollover or crash and help protect the user's head, neck, back, and limbs. A protective faring is also proposed to protect passenger's legs, improve in-air aerodynamics and maneuverability.

- Additional side support should be added to help keep the passenger and padding in the frame of the Phoenix. This does not have to be a heavy structural support, but simply an addition of connection points that would allow for webbing to be used.
- An overall reduction in weight is needed. With reserve parachutes the Phoenix 1.0 and 1.5 weigh approximately 64 and 71 pounds, respectively. Many of the items noted below will help to reduce weight (new frame design, investigation into composites and ultra-light metals such as titanium).
- Create a table for each chair that has the weight of each component. This will allow trainers and instructors to remove any components they feel unnecessary at the time.
- A custom seating system designed by Supracor will allow for increased comfort and adjustment for the passengers.
- Ti-lite products has indicated a willingness to provide removable wheels, quick release pins and increased flexibility along with a huge variety of tire and wheel options. Most of these components are interchangeable with modern wheel chairs.
- It is highly suggested that a rugged (knobby) tire not be used. The traction is not required and the aggressive surface has caused at least one abrasive injury to a user due to contact of their arms/elbows with the tire upon landing. The aggressive tire design has also resulted in tangling the riser lines.
- The brake, initially added for assistance when taking off and landing, was deemed unnecessary and possibly dangerous because it kept getting in the

way. The proportional brake was removed from the Phoenix 1.0 and 1.5. An "on-off" brake will be added to the Phoenix 2.0 to be used while stationary.

- Wheel chairs today can be found with features such as wheel fairings that can be pressed against the wheel to offer some amount of slowing/braking as well as protection for the passenger. This should be incorporated in the Phoenix 2.0 to achieve some level of braking when an "on-off" option would not work, such as prior to launch. These fairing should also be removable so that it does not hinder ingress/egress.
- The system design will be modified to facilitate the use of chrome-moly steel, which will increase the strength and durability and decrease weight. Some components to anchor shocks and other components for the Phoenix 1.5 were made out of chrome-moly steel to allow assembly and welding of the frame, resulting in a higher weight than for the Phoenix 1.0. A design to relocate and increase the efficiency of the anchor points will help reduce the overall weight of the Phoenix 2.0 while offering the higher strength of chrome-moly steel.
- Additional education, experience and training protocols will be developed to allow further progression of the Phoenix program. This will be handled primarily by the instructors, Mr. Sporrer and Mr. Greece. It is also expected that USHPA will adopt the Phoenix program as the official training regimen. This vote will take place in October 2012 when the USHPA Board of Directors meet in New York City.

- Future development in composite materials such as carbon fiber or ultra-lightweight steel such as titanium will allow for additional models to be developed. These models can be used during competitions and speed races where the reduction of weight is very important.
- A narrower frame will accommodate individuals more comfortably. While in Sun Valley it was apparent that the width of the chair made ingress/egress quite difficult. The original frame width of 26" was not needed and, in fact, failed to keep passengers secured in the chair. This caused some users to feel as though they were going to slip out. While the center strap of the harness prevented this, it was disconcerting for the users. After discussions with PVA students it was determined that a width of approximately 15", plus required padding, would be adequate. The team decided that 2" of padding for each side would be sufficient to make the passenger feel comfortable and secure resulting in a frame width of 19".
- A more ergonomic design under the passenger will create a clamshell effect increasing passenger comfort and security, and prevent the passenger from slipping forward.
- The use of a more simplistic design will decrease costs and allow for easier manufacturability. Increasing the number of bends and reducing welds will help in simplifying the design. This will be done in conjunction with reducing the components and anchor points required for the shocks. These changes will increase strength and rigidity of the frame.

- It is also proposed that analytical testing be performed to evaluate alternative shock absorber configuration and settings to optimize landing performance. Shock configurations similar to that found on modern mountain bikes should be evaluated.
- The addition of a reserve chute to the system will increase safety in case of a high altitude fall. The best style suited for this would be a large chest mount using the attachment points for the wing. This is required in case of issues with the main wing while flying. The reserve chute will allow for the chair and its passenger to return to earth as safely as possible.
- Use a four-wheel design with independent suspension similar to Phoenix 1.0 and 1.5. The four-wheel design and independent suspension in the two previous chairs has resulted in a good safety record. Alternative wheel designs will be evaluated for future "competition" systems.
- Modify the frame design for increased performance and comfort. The Phoenix 1.0 was built to mimic a wheelchair with a center of gravity that would allow the passenger to tilt the chair back. This ended up not being a desirable feature since it caused multiple tip-back issues, particularly upon landing. This will be corrected by moving the axles toward the rear, which will increase stability upon landing.
- Increase the front swing arm rake for increased performance with front impacts. While the benefit of this modification is not completely clear, it could be beneficial if the Phoenix were to impact a large rock or object in the

landing zone. It is the understanding of the team that the front shocks will act in a similar manner, dampening impacts with any landing zone obstacles.

- Required machining should be reduced to lower manufacturing costs and increase consistency in manufactured parts. Many parts were made using computer numerical control (CNC) mills and lathes. These parts were time consuming to make and generally heavy compared to the overall weight of the chair. It is proposed that a design to help facilitate the use of tools like the water jet metal cutter will lower the cost of machining, increase the precision of these parts and decrease weight.
- The use of snowboard bindings as foot rests will increase adjustability and allow increased accommodation for the height of passengers. It is important to have a footrest that is easily adjustable for each individual's foot/leg. This foot rest should allow for length, sliding in and out of the chair, to give taller passengers added comfort.
- The current foot restraints use the snowboard bindings and attach to a round tube, which allows rotation. The foot restraints should be designed so that they remain secure, which will eliminate the constant need for tightening and adjustment.
- Instructor Nick Greece has expressed concern that the ground clearance of the foot restraints is not sufficient and should be increased. This dimension has not yet been determined.
- Due to the size of the Phoenix 1.0 and 1.5 it is recommended that an overall more compact design be implemented. This will add to the comfort of the

chair and facilitate easier travel to and from the launch site. A later revision might also be collapsible so that it could fit in a sedan or smaller vehicle.

- It would be beneficial for measurements to be taken from any future frames after manufacturing. This will give a baseline for future measurements and comparisons after the parts have been in service.
- Instructor Nick Greece has requested that a total weight breakdown be done and included with each system. This breakdown will give a list of items and their weights (total weight should be determined and compared by the sum of all subitems). This will give the ability to drop weight and determine if certain items are even required.
- The ability to easily collapse the system for transportation and/or shipping would be highly beneficial.

Further evaluation and discussion will be required on many of these bullet points due to the impact they will have on the design of the Phoenix 2.0.

5.2.2 USHPA and the Phoenix

The Phoenix is being adopted by the United States Hang Gliding and Paragliding Association (USHPA). Because of this, the training program being developed by Mr. Sporrer and Mr. Greece will become the first and official training using the Phoenix system.

CHAPTER 6

CONCLUSION

6.1 Conclusion of the Phoenix Project

The Phoenix is an adaptive sport chair designed to allow persons with disabilities to safely experience the freedom, joys and sense of accomplishment of flight that paragliding offers, on the same level as able-bodied individuals as they soar through the air.

Without the assistance and help of many individuals this project would not be where it is today. Since January 2010 there have been multiple teams responsible for the design, development and manufacturing of the Phoenix system. The participation noted below does not include time spent by test pilots or instructors, outside vendors, or work by other entities associated with the training camps.

The involvement of the original University of Utah team and the development and manufacturing of the Phoenix 1.0 is as follows:

- Bryon Densley was responsible for project management, frame design, SolidWorks development along with a large portion of machining and lathe work during manufacturing. This accounted for approximately 35% of the workload for which the University of Utah team was responsible.
- Christopher Graves did all design and manufacturing of the swing arms as well as feedback and troubleshooting on the remaining design portions. This

accounted for approximately 35% of the workload for which the University of Utah team was responsible.

- Benjamin Davidson interacted with vendors to ensure the work done by others was completed on time as well as being the primary author of a report. This accounted for approximately 15% of the workload for which the University of Utah team was responsible.
- Travis Smith was primarily responsible for manufacturing and working with the frame bender/welder to attach the components machined by Bryon Densley. This accounted for approximately 15% of the workload for which the University of Utah team was responsible.

The involvement of the original University of Utah team and the development and manufacturing of the Phoenix 1.5 is as follows:

- Bryon Densley was responsible for project management, SolidWorks development, ordering and manufacturing. This accounted for approximately 40% of the workload for which the University of Utah team was responsible.
- Dr. Andrew Merryweather played a critical role in managing manufacturing personnel, design feedback, manufacturing of water jet components, assembly and shipping the Phoenix as needed. This accounted for approximately 40% of the workload for which the University of Utah team was responsible.
- Faris Ali, a graduate student, played a large role in manufacturing and machining as required. Assistance with assembly and shipping was also provided. This accounted for approximately 20% of the workload for which the University of Utah team was responsible.

One of the most important lessons learned through the Phoenix program is the difficult task of making the Phoenix safe. Even with the many safety levels and precautions added to the chairs, unexpected things can happen. Although paragliding is a high risk sport, at no time should subject students be exposed to any avoidable risk. Existing chairs along with future chairs will continue to progress and safety modifications will be added to help combat both expected and unexpected dangers.

Many milestones have been reached and several hundred flights have been completed, including solo and tandem flights, with both able-bodied and disabled individuals. A training program and protocol is currently being developed by world class instructors. Five individuals have reached P-1 certifications, two of whom will have P-2 certifications in September 2012, and worldwide interest in the Phoenix has been a positive side effect.

The Phoenix program could not have progressed to where it is today without the volunteer students and pilots, ABLE Pilot, and University of Utah students and faculty. Continued improvements, additional flights and even more revisions will continue long into the future.

APPENDIX A

UNIVERSITY OF UTAH TEAM

The University of Utah team consisted of the following individuals:

- Dr. Donald Bloswick, Research Professor
  - Technical Direction, Program Lead
- Dr. Andrew Merryweather, Assistant Professor
  - Technical Direction, Assistant Program Lead
- Bryon Densley, Graduate Student
  - Project Management, Design
- Other important members of the Phoenix program:
  - Faris Ali (Manufacturing)
  - Senior Design Team
    - Christopher Graves (Design, Manufacturing, Welding)
    - Benjamin Davidson (Design, Analysis)
    - Travis Smith (Manufacturing)

APPENDIX B

ABLE PILOT TEAM

The ABLE Pilot team consisted of the following individuals:

- Rob Sporrer, Lead Instructor
    - Ground School Instruction
    - Towing Instruction/Assist
    - Tandem Instruction
- Nick Greece, Instructor
    - Media Relations
    - Tandem Instruction
    - Photographer and Videographer
- Other volunteers assisting with the Phoenix program
    - Chuck Smith
    - Tim Meehan
    - Mark Gaskill

APPENDIX C

CALCULATIONS

Aluminum 6061-T6:

Tensile Yield Strength = σ_y = 40000psi (ASM, 2012)

Density = ρ = 0.0975 lb/in^3 (ASM, 2012)

<u>WALL THICKNESS = 0.083"</u>

$t = 0.083$ in

$r_o = 0.5$ in

$r_i = r_o - t = 0.417$ in

$A = \pi(r_o^2 - r_i^2) = 0.239 \text{ in}^2$

$F_{allowable} = \sigma_y \cdot A = 9.564 \times 10^3$ lbf

$I = \frac{\pi}{4}(r_o^4 - r_i^4) = 0.025 \text{ in}^4$

$M_{allowable} = \frac{\sigma y \cdot I}{ro} = 2.027 \times 10^3$ in·lbf

$m = \rho \cdot V = 0.0975 \text{ lb/in}^3 \cdot (\pi \cdot h(r_o^2 - r_i^2)) = 0.27976$ lb/ft

<u>WALL THICKNESS = 0.065"</u>

$t = 0.065$ in

$r_o = 0.5$ in

$r_i = r_o - t = 0.435$ in

$A = \pi(r_o^2 - r_i^2) = 0.191 \text{ in}^2$

$F_{allowable} = \sigma y \cdot A = 7.637 \times 10^3$ lbf

$I = \frac{\pi}{4}(r_o{}^4 - r_i{}^4) = 0.021$ in^4

$M_{allowable} = \frac{\sigma y \cdot I}{ro} = 1.677 \times 10^3$ in·lbf

$m = \rho \cdot V = 0.0975$ lb/in^3 $\cdot(\pi \cdot h(r_o{}^2 - r_i{}^2)) = 0.22339$ lb/ft

APPENDIX D

FIRST OFFICIAL PRESS FOR THE PHOENIX 1.0

On May 30th, 2010 KSL reported

People who don't have the ability to walk can now discover what it feels like to fly. ABLE Pilot, a chapter of the U.S. Hang Gliding and Paragliding Association, along with the University of Utah Department of Mechanical Engineering, have developed adaptive paragliding equipment that allows people with spinal cord injuries and paralysis to fly with minimal assistance. The group unveiled the Phoenix One harness at the Utah AAA Sprints competition Saturday at the Point of the Mountain State Park. "This allows us to do regular instruction with persons with paralysis," says Mark Gaskill, vice president of the U.S. Hang Gliding and Paragliding Association. "It also allows us to take people who may be quadriplegic, who might not be able to fly completely independently up on tandems." Phoenix One has wheels that act as landing gear, just like a pair of legs would. The engineering marvel took its maiden flight Sunday.

Along with the launch of the new equipment, ABLE Pilot also introduced a new training program designed for people in wheelchairs. Already, six people with spinal cord injuries have signed up to fly next week (KSL, 2010).

APPENDIX E

SUN VALLEY NEWSPAPER ARTICLE

On August 8th, 2011, Spinal Cord Injury Veterans Learn to Paraglide. ME Department and ABLE Pilot team up to help all people learn to fly.

SUN VALLEY, ID – Today, five veterans are taking to the skies to learn to paraglide. What is the different about these veterans is that they all have spinal cord injuries (SCI) and do not have the use of their legs. They will be learning to fly in an adaptive flight chair at a training camp in Sun Valley, enabling the veterans to, eventually, fly solo.

In this week's training camp, the veterans will be flying in both the original flight chair, the Phoenix 1.0, and an improved flight chair, the Phoenix 1.5. The original Phoenix 1.0, was developed and built under the direction of Dr. Don Bloswick by four M.E. undergraduate students. Professor Bloswick and design team member Bryon Densley will be at the training camp on Tuesday and Wednesday working with the vets. Densley was on the original Phoenix 1.0 team along with M.E. undergrads Chris Graves, Travis Smith, and Ben Davidson. All four students graduated with Bachelor's degrees in Mechanical Engineering in the Spring of 2010, but Densley is continuing to work on the Project for his Master's degree research. Dr. Andrew Merryweather and Faris Ali, who recently started his Master's Degree in Mechanical Engineering at the U, were instrumental in the design and fabrication of the new Phoenix 1.5.

Training for the five SCI Veterans began this morning and will continue until Wednesday. During the first day of training, the vets will be learning about paragliding: how the paraglider works and functions and how to pilot it. Those skills will then be applied as they learn how to paraglide about 3 feet off the ground. The next step is to take several tandem flights with certified instructors. The training team hopes to have the veterans off the ground and flying solo by Wednesday.

Mark Gaskill, from ABLE Pilot, is directing the SCI Veteran training course in Sun Valley. He is a trained solo and tandem pilot and has been working in the area of paragliding for disabled persons for several years. Gaskill has developed the overall paragliding training program for persons with disabilities and was the person who initially came to the U of U team with the idea to develop the adaptive flight chair.

ABLE Pilot is an organization committed to "getting people with spinal cord injuries, amputations, and neuromuscular diseases safely into the air, piloting, and flying with the minimum amount of assistance" (Mechanical Engineering U of U, 2012).

APPENDIX F

NEW YORK TIMES ARTICLE

On September 4th, 2011 NYT reported, Accustomed to Wheels, Thrill-Seeking Injured Veterans Take Wing.

KETCHUM, Idaho – Searching for ways to keep his adrenaline pumping after a motorcycle accident forced him out of the military and into a wheelchair, Darol Kubacz recast himself as something of a pioneer of extreme sports.

First he took up downhill skiing, racing and jumping with such abandon that he broke his spine a second time. After a painful rehab he started mountain biking and scuba diving, and even hauled his barrel-chested frame up Mount Kilimanjaro.

Last month, that risks-be-damned pursuit of adventure drew Mr. Kubacz from his home in Arizona to a rocky mountaintop here to do something a pair of working legs never would have allowed anyway — take flight.

“Like the Marines say,” he said, “adapt and overcome.”

And with the crunch of sagebrush under a new, modified wheelchair, Mr. Kubacz, 37, and his instructor rolled down the slope and then soared into the expanse, his paraglider canopy lofting in the breeze.

For generations, returning soldiers with serious disabilities, whether sustained in combat or in risky off-duty pursuits like motorcycling, found limited — and relatively tame — options for athletic recreation. But the latest generation of disabled veterans are increasingly returning to the thrill-seeking activities they enjoyed before their injuries.

As they expand the range of so-called adaptive sports to surfing, rock climbing and white-water rafting, with the help of new technology and public and private financing, these veterans have worked to prove that a wheelchair does not necessarily require its occupant to stick to level ground.

"They are doing things we never thought possible 10 years ago," said Kirk Bauer, executive director of Disabled Sports USA. Back when Mr. Bauer lost a leg in Vietnam, the organization had one chapter teaching one sport (skiing); today it has more than 100 chapters and offers 30 sports.

"They love speed, they love challenge, they love risk," Mr. Bauer said. "And they are really pushing the envelope."

That was the clear goal for the five paraplegic military veterans, none injured in combat, who arrived here last month to learn to paraglide, a type of unpowered flight similar to hang gliding but using equipment that more closely resembles a parachute.

Pilots launch on foot and then sit in a harness below a canopy, which can be steered with hand controls. Those with experience can stay aloft for hours before landing, typically in an open field.

Though they are not the first paraplegics to paraglide, they were the first being taught from scratch using a new device called the Phoenix, with a wheelchair in place of a normal harness. The eventual goal is for participants to pursue the high-altitude sport on their own, perhaps even at a competitive level.

"I knew I could do it with the right equipment, but I just didn't know whether anyone had been brave enough to try it yet," said Erik Burmeister, 37, who was paralyzed in a motorcycle accident.

After his injury, Mr. Burmeister learned to ski and scuba dive, doing each as often as possible. One day, at home in Pennsylvania, he searched the Internet for an activity that would replicate the thrill of his dozen parachute jumps with the Army and stumbled upon information about the Able Pilot program, the group organizing the first wheelchair paragliding class. He was one of the five chosen from more than 100 applicants.

"We've all accepted that our mobility is limited," he said. "But it's a constant grind to drag our wheels around. In all these sports, moving is effortless again. The sense of freedom is just so incredible."

The four-day training program served up constant reminders of the inevitable trial and error that comes with learning a new sport, particularly for someone in a wheelchair. During the introductions, the participants were told they were not hamsters in some experiment. Still, they embraced the role of putting their bodies on the line. By the end, four of the five had tipped or rolled over on landing; the fifth crashed on an aborted takeoff.

The volunteer instructors, as well as engineers from the University of Utah, took notes as the students suggested ways to change teaching methods and improve the wheelchair design to better fit their needs.

The program was paid for with grants from the Paralyzed Veterans of America and the Christopher and Dana Reeve Foundation, with help from the local Sun Valley

Adaptive Sports. A number of other groups declined to offer support, calling the program too risky.

"Yes, paragliding is inherently dangerous," said Mark Gaskill, a veteran and a paraglider who started the Able Pilot program after taking several paraplegics on tandem flights. "Life is dangerous. These guys understand the risks. They understand what injury can do. But wheelchair tennis isn't for everyone."

The classes, which mostly consisted of on-the-ground training, started before sunrise, with the group hauling themselves out of their wheelchairs and into vans for the ride into the mountains. Each day students also were taken on tandem flights with the volunteer instructors, during which they were able to fly the gliders themselves.

"I didn't think I'd ever fly again," said Anthony Radetic, 32, a former helicopter pilot who broke his back when his motorcycle was struck by a car.

For years after his injury he was too embarrassed to even go outside, particularly after he was forced to leave the Army. That changed with his introduction to adaptive sports: Jet Skiing, downhill skiing and hand cycle racing (he has competed in numerous marathons). And he even retrofitted his motorcycle, a Ducati, so he could continue to ride the back roads of his rural Alabama community.

This type of transformation is one of the reasons the Department of Veterans Affairs has enthusiastically supported what leaders there describe as an exponential increase in extreme sports, providing money for equipment and training. As risky as the activities may be, they are viewed as preferable to the drinking and depression that often follow life-altering injuries.

“It’s more than a bunch of yahoos going out and having a good time,” said Richard Stieglitz, who oversees physical health and wellness for the Wounded Warrior Project, which provides programs for injured service members. “We use it as a tool to show them they can do anything they want.”

After a bumpy van ride to the top of the mountain used for the paraglider launches, Ernie Butler, 59, executive director of the northwest chapter of the Paralyzed Veterans of America in Washington, readied himself for his first flight in the Phoenix.

He pulled a fitted helmet out of a small bag. The last time he put it on was to sky dive 16 years earlier, he said, “the day I bounced.” His parachute had become tangled when it was hit by another sky diver; after he hit the ground he had more than 220 fractures.

His wisecracking betrayed no nervousness, just anticipation. “It’s been a long time since I had my knees in the breeze,” he said.

And then with a joyful holler he rolled down the slope and took off, whooping as he passed the group readying the second chair for launching (The New York Times, 2011).

APPENDIX G

SUN VALLEY PARTICIPANTS

There were numerous volunteers and organizations that made Sun Valley such a success. This would include the Paralyzed Veterans of America (PVA), the ABLE Pilot team, University of Utah team and many other family and friends.

Ernie Butler: 57 years old and living in Seattle, Washington. Ernie was a U.S. Air Force Special Operations Pararescueman, sport skydiver and former member of the U.S. skydiving team with over 6000 skydives and 120 hours of free fall. Ernie was paralyzed in a skydiving accident at the 1995 World Parachuting Championships in Gap, France. Since this happened Ernie has continued to be involved in sports such as: kayaking, cycling, shooting sports (pistol and shotgun) and hunting. For the past 6 years Ernie has been the Executive Director of the NW Chapter of Paralyzed Veterans of America and founded Camp ACCESS Foundation, a summer sports and recreation camp (now in its 10^{th} year) for children with spinal cord injury or disease.

Anthony Radetic: 32 years old, from Abbeville, Alabama. Anthony is an Army Combat Veteran of Operation Iraqi Freedom and Operation Enduring Freedom. Before being injured, Anthony lived life on the edge. He drove sports cars, served in the Army as a Blackhawk Helicopter pilot and was a dedicated Special Forces soldier. After a motor vehicle accident he had to find new ways to live the fast-paced life he had grown accustom to. While receiving care the Tampa VA Medical Center, Anthony was encouraged by staff to looking into attending some of VA's National Rehabilitative Special Events. In 2009, he attended the National Veterans Wheelchair games for the first time, as well as the National Disabled Veterans Winter Sports Clinic and the National Veterans Summer Sports Clinic. Anthony's experiences competing in the world of adaptive sports lit a spark for him. One of the proudest moments for Anthony was serving as a mentor for "Kids Day" at the 2010 Games in Denver. Anthony has a little girl of his own, and loves inspiring children with disabilities to get involved with adaptive sports.

Darol Kubacz: lost the use of his legs in the line of duty as a US Army soldier. Paralyzed from the chest down, he chose to take what others consider tragedy and turn it to triumph. A new opportunity to truly experience and appreciate life after such a radical change was how he began long distance hand cycling, alpine skiing, scuba diving, a real-estate management company, and international volunteer ventures. After nine years of pushing the limits of his ability, he broke his neck while freestyle skiing and spent the following 16 weeks in a halo. Darol considers this second injury a gift: a second chance to adapt and overcome. Thanks to the "down time" he has since climbed Mt. Kilimanjaro and aspires to be an independent cross-country paraglider pilot. Darol's primary focus is sharing his passion for health and outdoor adventure recreation, with those who may not have the opportunity or support.

Erik Burmeister: 37 years old, born on the West Coast but grew up mostly in Texas and Indiana. Erik served with the Army National Guard and was trained as a medic. Erik really enjoys mono-skiing in the winter. Erik is certified in scuba diving, however, does not have the opportunity to enjoy the diving close to where he lives. Erik wanted learn a sport that he could enjoy locally during the warmer months. He says paragliding will be a perfect fit and has dreamed of paragliding for years, even before he was paralyzed. Continuing to be active after becoming paralyzed is very important, and he is so grateful for opportunities that he has been given to help stretch his limits.

Brent King: An Airborne Infantry Officer in the Army and broke his back doing an obstacle course at Fort Benning. Brent is an avid snow mono-skier that hits double black diamond runs. Brent has worn out three arm bikes and now working on taking the life out of the fourth arm bike. Brent played in the Wheelchair Basketball National Championships with his team placing 3rd in the nation. Brent is ready and willing to take on new challenges. Brent started his Light Sport Aircraft introduction at the age of 22 as he flew many hours in a Tri-Pacer and Cherokee airplanes with a family friend. Brent was often allowed to launch and fly as much as he desired with him taking the controls on landing.

APPENDIX H

3D IMAGES OF THE PHOENIX SYSTEM

In order to be cost-effective, move forward quickly, and prove concepts prior to fabrication these solid models were analyzed and dynamically tested. This approach assured that there were no interferences and the dimensions were accurate. It also allowed for a weight approximation for the finished product. Figures (12-15) are several views of the finished 3D model created in SolidWorks.

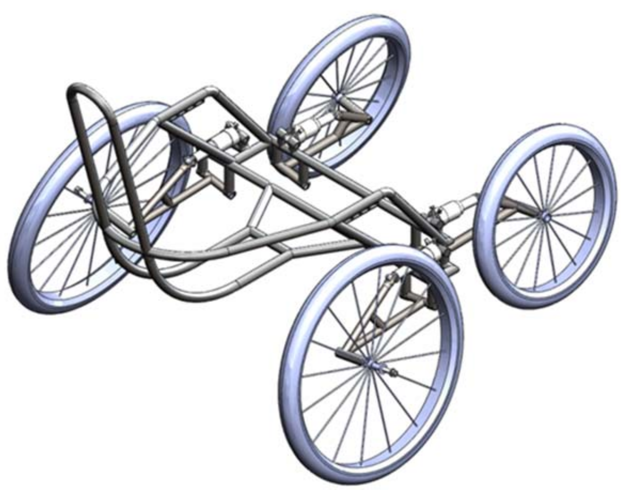

Figure 12: Top Isometric View, 3D Image (Densley, 2011)

Figure 13: Front Isometric View, 3D Image (Densley, 2011)

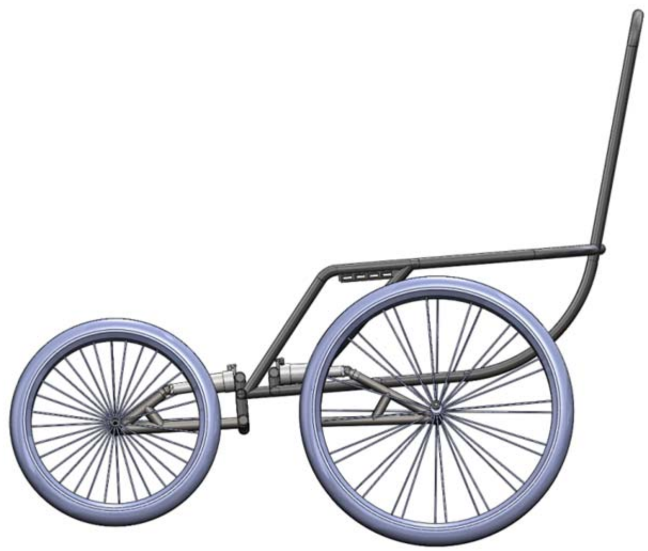

Figure 14: Side View, 3D Image (Densley, 2011)

Figure 15: Front View, 3D Image (Densley, 2011)

APPENDIX I

IMAGES OF THE PHOENIX SYSTEM COMPONENTS

The following figures (16-22) are from the completed Phoenix system.

Figure 16: Front view Phoenix 1.0, Prior to First Launch (Densley, 2011)

Figure 17: Underbody of the Frame (Densley, 2011)

Figure 18: Swing Arm Attachment Location (Densley, 2011)

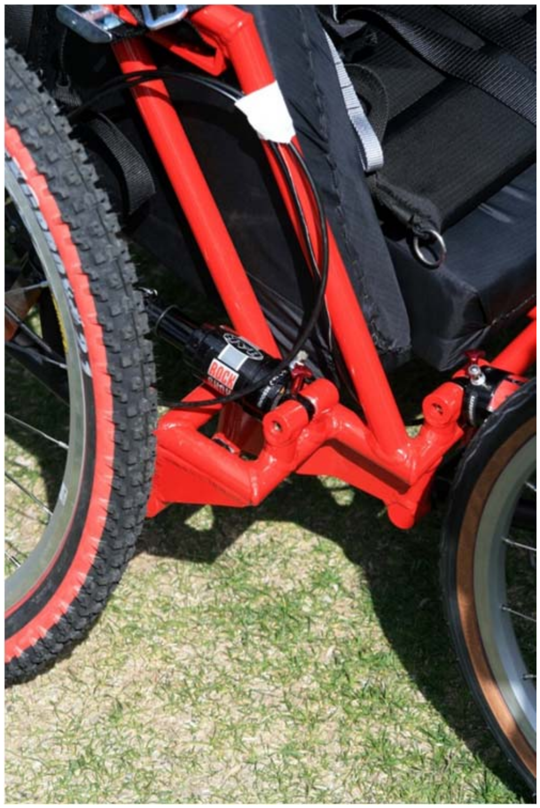

Figure 19: Right Side (Densley, 2011)

Figure 20: Shock Mounts and Gussets (Densley, 2011)

Figure 21: Front Isometric View (Densley, 2011)

Figure 22: Disc Brakes (Before Removal) (Densley, 2011)

APPENDIX J

BEGINNER PARAGLIDING RATING (P-1)

The following are requirements from the USHPA Pilot Proficiency System.

- Complete basic ground school.
- Layout and preflight of canopy and harness.
- Demonstrates canopy handling skills sufficient to launch – under control.
- Demonstrate methods that pilot is properly connected to the canopy.
- Launch unassisted (modified for Phoenix system).
- Airspeed recognition and control.
- Ability to recognize and understand how different wind conditions will affect their flights.
- On each flight, demonstrate proper post-landing procedure.
- Demonstrate an understanding of the importance of proper packing, storage, and care of the canopy.
- The pilot shall use good judgment and have a level of maturity commensurate with the rating.
- Must pass the USHPA Beginner Paragliding written exam.

- Must agree to all the provisions of the USHPA standard waiver and assumption of risk agreement for the Beginner and deliver an original signed copy to the USHPA office.

APPENDIX K

NOVICE PARAGLIDING RATING (P-2)

The following are requirements from the USHPA Pilot Proficiency System.

- Logged Requirements
    - Receives ground school theory as outlined in the ICP Manual.
        - Weather
        - Launches
        - Danger Signs
        - Landing
        - Equipment
        - Site Orientation
    - Demonstrate Skills and Knowledge
        - Layout and preflight of the canopy, harness and backup reserve parachute.
        - Gives a reliable analysis of general conditions of the site and self, and a flight plan including flight path, areas to avoid in relation to the wind flow, and obstacles to stay clear of.
        - Demonstrate 5 consecutive forward inflations with a visual check of the canopy each time.

- Demonstrate 5 consecutive controlled reverse inflations with proper surge dampening.
- Demonstrate controlled kiting of a glider overhead for 2 minutes in a steady wind.
- Demonstrate 2 clean, smooth reverse inflations/reversals prior to launch (modified for the Phoenix system).
- With each flight, demonstrate a method of establishing that the pilot is properly connected to the glider, with cleared lines and risers just prior to inflation.
- Demonstrate 2 successful, aggressive, confident inflations/launches, where the wind is at least 15 degrees cross to straight up the hill in wind not exceeding 5 mph (modified for the Phoenix system).
- Demonstrate 2 no-wind (0-5 mph) inflations/launches (modified for the Phoenix system).
- Demonstrate how to brief and instruct a ground crew and explain when an assisted launch is necessary.
- Demonstrate 2 high-wind (10-15 mph) inflations/launches (modified for the Phoenix system).
- Demonstrates flight with smooth variation in airspeed, from above minimum sink to fast flight, while maintaining a heading.

- Demonstrates flight showing the ability to comfortably and precisely slow the glider to minimum sink and smoothly increase to normal airspeed while maintaining a heading. The pilot should not slow the glider to near the stall speed.
- Demonstrates flight(s) along a planned path alternating ‘S’ turns of at least 90 degree change in heading. Flight heading need not exceed 45 degree from straight into the wind. Turns must be smooth with controlled airspeed, ending in safe, stand up landings on a heading.
- Demonstrates 180 degree turns in both directions, and at various speeds and bank angles.
- Demonstrates hands-off flying, one handed flying skills, weight-shift turns, and rear-riser turns.
- Demonstrates symmetric and asymmetric tip folds for increased descent rate.
- Demonstrates the ability to judge and allow for proper clearance from a ridge and other vehicles.
- Demonstrates 5 landings within 25’ of a target (or optional landing task), safe, smooth.
- Explains proper strong wind landing procedures and how to keep from being dragged back.
- Explains correct canopy maintenance.
- Explains how to lengthen and shorten the flight path.

- Explains the right of way traffic rules.
- Demonstrates the proper use of a speedbar/accelerating system.
- Demonstrates reserve deployment while hanging in a harness in simulated turbulence or malfunction conditions.
- Gives a thorough verbal demonstration of knowledge of how to:
  - Maintain directional control during and correct for an asymmetric wing fold of 25% of the wing span.
  - Fly at minimum sink while precluding any chance of inadvertent stall or spin, particularly when flying through lift, sink or in conjunction with making turns.
  - Increase descent rate and/or forward speed.
- Demonstrates proper and effective PLF technique.
- Must pass the USHPA Novice Paragliding written exam.
- Must agree to all the provisions of the USHPA standard waiver and assumption of risk agreement for the Novice rating and deliver an original signed copy to the USHPA office.

APPENDIX L

FMEA OF PHOENIX SYSTEM

The following is the Failure Mode and Effects Analysis performed on the Phoenix system to help identify potential risks. Identifying these risks was required to help ensure the safety of the system.

IDENT. NO.	ITEM & FUNCTIONAL IDENT.	FAILURE CAUSE	FAILURE MODE	FAILURE EFFECT	TARGET	RISK ASSESSMENT		
						SEV	PROB	RISK CODE
Frame	Weldment	Impact	Weakening of the welds	Phoenix falls apart injuring passenger	V	L	M	D3
		Fatigue	Weakening of the welds		R	L	L	D3
		High Stress (Overall)	Cracking of the welds	Destruction on future impact	R	M	L	D2
		Isolated Stress (one wheel, etc)	Cracking of the welds		R	M	L	D2
			Fracture	Phoenix falls apart injuring passenger	R	M	M	D2
			Deformation	Injures passenger	R	M	L	D3
		Corrosion	Weakening of the welds	Phoenix falls apart injuring passenger	R	L	L	E3

IDENT. NO.	ITEM & FUNCTIONAL IDENT.	FAILURE CAUSE	FAILURE MODE	FAILURE EFFECT	TARGET	RISK ASSESSMENT		
						SEV	PROB	RISK CODE
			Degradation of surface finish	Abrasions to passenger	R	L	L	D4
			Frame failure on landing	Injures passenger	R	L	L	E2
		Sharp Edges	Cuts passenger		V	L	L	E2
	Footrest	Impact	Deformation	No leg support, leg injury on landing	V	L	M	D3
		High Stress shears connection pins	Falls Off		E	L	L	D2
		Vibration CAUSES - connection pins to fall out	Becomes loose	Damages footrest for future use	V	L	L	D3
			Falls Off	No leg support, leg injury on landing	V	L	L	D2
		Sharp Edges	Cuts passenger	Injures passenger	E	M	L	E2
		Incorrect Installation	Becomes loose	Damages footrest for future use	P	L	M	D4
			Falls Off	No leg support, leg injury on landing	P	L	L	D2
	Detachable Roll bar	Phoenix rolls on landing	Collapses	Injures passengers head/neck/spine	V	H	L	E1
			Deformation	Damages roll bar for future use	V	L	M	E4

IDENT. NO.	ITEM & FUNCTIONAL IDENT.	FAILURE CAUSE	FAILURE MODE	FAILURE EFFECT	TARGET	RISK ASSESSMENT		
						SEV	PROB	RISK CODE
		No roll bar installed	Phoenix smashes rider	Injures passengers head/neck/spine	P	H	L	E2
		Falling Objects	Deformation	Damages roll bar for future use	V	L	L	E3
		Sharp Edges	Cuts lines going to the wing	All passengers plummet to death	E	H	M	E1
		Incorrect Installation	Ineffective when needed	Injures passenger	P	L	L	E3
			Falls Off	Injures passengers head/neck/spine	P	M	L	E3
			Deformation	Injures passenger	P	L	L	E3
	Detachable Wheelie bar	Impact	Wheelie bar deforms	Phoenix tips backward	V	L	M	D3
		Not attached	Passenger falls backward	Injures passengers head/neck/spine	P	M	L	D3
		Vibration	Becomes loose	Damages wheelie bar for future use	V	L	M	D4
			Falls Off	Phoenix tips backward	V	L	L	D3
		Incorrect Installation	Ineffective when needed		P	L	L	D4

IDENT. NO.	ITEM & FUNCTIONAL IDENT.	FAILURE CAUSE	FAILURE MODE	FAILURE EFFECT	TARGET	RISK ASSESSMENT		
						SEV	PROB	RISK CODE
			Becomes loose	Damages wheels for future use	P	L	L	D4
			Falls Off	Phoenix tips backward	P	M	L	D3
	Swing arms	Impact	Deformation	Damages swing arm for future use	V	L	M	D3
			Fracture	Phoenix rolls injuring passenger	V	L	L	D2
		Vibration	Loosening of connection bolts	Damages swing arm for future use	E	M	M	D3
		Incorrect Installation	Ineffective on landing	Phoenix rolls injuring passenger	P	L	M	E3
	Wing connection location	Impact	Cuts lines going to the wing	Phoenix falls or CAUSES - balance issues	V	H	L	E3
		Welding failure	Offsets balance of setup		R	M	M	E2
		Material failure	Offsets balance of setup		R	M	L	E2
		Vibration	Fatigue in material		V	M	L	E3
		Sharp Edges	Cuts lines going to the wing		E	H	L	E1

IDENT. NO.	ITEM & FUNCTIONAL IDENT.	FAILURE CAUSE	FAILURE MODE	FAILURE EFFECT	TARGET	RISK ASSESSMENT		
						SEV	PROB	RISK CODE
		Incorrect Installation	Phoenix falls from rider	Passenger injury upon landing	P	L	L	E2
	Shocks	Impact	Too hard		V	L	M	D3
		Incorrect pressure settings	Over extends causing it to bottom out		P	L	M	D3
			Too stiff becoming ineffective		P	L	M	D3
		Incorrect Installation	Bolt shears	Phoenix rolls injuring passenger	P	L	M	E2
Wheels	Quickies	High stresses from hard landing	Crushes the wheel	Phoenix rolls injuring passenger	E	L	M	D3
			Whips rider forward or back	Passenger injury upon landing	E	M	L	D2
		Extreme Temperatures (cold)	Fractures rims		E	L	L	E3

IDENT. NO.	ITEM & FUNCTIONAL IDENT.	FAILURE CAUSE	FAILURE MODE	FAILURE EFFECT	TARGET	RISK ASSESSMENT		
						SEV	PROB	RISK CODE
		Extreme Temperatures (hot)	Rubber rips from rim on landing	Phoenix rolls injuring passenger	E	L	L	E3
		Vibration	Falls Off		V	M	L	E1
		High Stress	Landing too hard	Passenger injury upon landing	E	L	L	D3
		Incorrect Installation	Falls Off	Phoenix rolls injuring passenger	P	M	M	D2
	Axles	High stresses from hard landing	Deformation	Damages axles for future use	E	L	M	E2
			Connection method fails	Phoenix rolls injuring passenger	E	L	L	E3
		Vibration	Connection method fails		V	L	L	E3
		Incorrect Installation	Connection method fails		P	L	L	E3

IDENT. NO.	ITEM & FUNCTIONAL IDENT.	FAILURE CAUSE	FAILURE MODE	FAILURE EFFECT	TARGET	RISK ASSESSMENT		
						SEV	PROB	RISK CODE
	Camber	Angle	Too much angle causing issues on landing		R	L	L	E4
			Not enough angle causing issues on landing		R	L	L	E4
	Single brake lever for two wheels	Not secured	Loses track of brake	Uncontrollable rolling while on ground injuring passenger	P	L	H	D3
			Brake tangles in wheel upon landing	Phoenix rolls injuring passenger	P	L	H	D2
		Vibration	CAUSES - brake handle to become unsecured (on ground)	Uncontrollable rolling while on ground injuring passenger	V	M	H	E3
			CAUSES - brake handle to become unsecured (in air)	Nothing, not used in landing	V	L	L	E4
	Tire	High Stress upon landing	Collapses	Phoenix rolls injuring passenger	E	L	M	E3

IDENT. NO.	ITEM & FUNCTIONAL IDENT.	FAILURE CAUSE	FAILURE MODE	FAILURE EFFECT	TARGET	RISK ASSESSMENT		
						SEV	PROB	RISK CODE
		Rough Terrain	Sharp objects punctures and flattens	Passenger injury upon landing	E	L	M	D3
			Large rocks impact and crush	Phoenix rolls injuring passenger	E	M	M	D2
	No redundant braking method	Cables damaged on take off	No braking on take off	Uncontrollable rolling while on ground injuring passenger	R	M	M	E3
			No braking on landing	Nothing, not used in landing	R	L	L	E4
Harness	Padding	Not secured	Falls off	Passenger injury upon landing	R	L	L	E4
		Moisture	Gets wet	Uncomfortable for passenger	E	L	L	C4
			Becomes moldy		E	L	L	E4
	Seating	Impact	Cracks seat	Passenger injury upon landing	V	L	M	E4
			Falls apart		V	L	L	E3

IDENT. NO.	ITEM & FUNCTIONAL IDENT.	FAILURE CAUSE	FAILURE MODE	FAILURE EFFECT	TARGET	RISK ASSESSMENT		
						SEV	PROB	RISK CODE
		Vibration	Connection method fails	Phoenix falls from passenger	V	L	L	E3
	Connection to Frame	High Stress	Connection method fails		E	L	L	E3
			Divider between balance point fails	Phoenix falls or CAUSES - balance issues	E	L	L	E2
	Passenger Seatbelt	High Stress	Connection method fails	Passenger falls from harness	E	H	L	E1
Wing	Wing	Impact	Rips wing	All passengers plummet to death	V	H	L	D2
		Falling Objects	Rips wing		V	H	L	E2
			Tangles lines		V	H	L	E2
		Collides with environmental objects	Rips wing		V	H	M	D2
			Tangles lines		V	H	M	D2
		Sharp Edges	Rips wing		E	H	L	E2
			Cuts lines going to the wing		E	H	L	E2
		Incorrect Installation	Tangles lines		P	H	M	E2

IDENT. NO.	ITEM & FUNCTIONAL IDENT.	FAILURE CAUSE	FAILURE MODE	FAILURE EFFECT	TARGET	RISK ASSESSMENT		
						SEV	PROB	RISK CODE
		Incorrect Usage	Wing falls apart		P	H	M	E2
	Lines	Snagged	Tangles lines		E	H	M	E2
			Cuts lines		E	H	M	E1
		Incorrect lines	Ineffective usage		E	H	L	E2
	Breakaway Connection to Harness	Activated when not needed	Wing to break away from setup	Balancing issues	P	H	M	D2
		Operator Error	Not activated	Passenger injured when wing is not detached as needed	P	M	M	D2
	Size	Wing too large	Overpowers setup	All passengers plummet to death	E	H	L	E2
		Wing too small	Not enough lift for setup		E	H	L	E2
Human	Human Error	Design induced errors	Issues upon landing	Passenger injury upon landing	P	L	L	E3
			Issues during take off	Passenger injury during takeoff	P	L	L	E3
			Issues during flight	Loss of Phoenix	P	M	L	E3
				All passengers plummet to death	P	H	L	E2

IDENT. NO.	ITEM & FUNCTIONAL IDENT.	FAILURE CAUSE	FAILURE MODE	FAILURE EFFECT	TARGET	RISK ASSESSMENT		
						SEV	PROB	RISK CODE
	Operator Error	Untrained	Issues upon landing	Passenger injury upon landing	P	L	L	E3
			Issues during take off	Passenger injury during takeoff	P	L	L	E3
			Issues during flight	Loss of Phoenix	P	M	L	E3
				All passengers plummet to death	P	H	L	E2

APPENDIX M

RISK ASSESSMENT MATRIX

The following risk assessment matrix was used in determining the risk assessment section of the FMEA.

Severity of Consequences	**Probability of Mishap**					
	Impossible (F)	Improbable (E)	Remote (D)	Occasional (C)	Probable (B)	Frequent (A)
Catastrophic (I)	3	3	2	1	1	1
Critical (II)	3	3	3	2	1	1
Marginal (III)	3	3	3	3	2	2
Negligible (IV)	3	3	3	3	3	3

Risk Zones	
1	= Imperative to suppress risk to lower levels
2	= Operation requires written , time-limited waiver, endorsed by management
3	= Operation permissible

APPENDIX N

FREQUENTLY ASKED QUESTIONS FOR BIKE SUSPENSIONS

Below are some common symptoms to bike suspension issues taken directly from the website of FOX (FOX, 2012). FOX has created a cause and effect to help provide tips and solutions to correct the behavior of the shocks; it is included below for convenience.

1. Not using full travel, feels harsh, poor traction while making turns
    1. CAUSES - Overly stiff springs or compression damping
    2. SOLUTIONS - Lower air pressure; reduce compression damping; softer coil springs
2. Bottoms, soft throughout travel
    1. CAUSES - Spring rate too low throughout travel, or too little compression damping
    2. SOLUTIONS - More air pressure; increase compression damping; stiffer Coils Springs
3. Excessive sag, feels soft initially but doesn't bottom
    1. CAUSES - Initial spring rate or preload too low; spring too progressive
    2. SOLUTIONS - Add air pressure or increase spring preload
4. Harsh over small bumps but uses full travel
    1. CAUSES - Initial spring rate or preload too high, springing not progressive enough, or too much compression damping

   2. SOLUTIONS - Lower air pressure or install softer springs; reduce compression damping; reduce spring preload
5. Takes first bump in a series well but harsh over later bumps, poor traction in washboard corners
   1. CAUSES - Too much rebound damping
   2. SOLUTIONS - Reduce rebound damping if adjustable - Non adjustable - reduce oil weight
6. Too Much Compression
   1. SYMPTOM - Ride is harsh, but not as bad as too much rebound. As speed increases, so does harshness. Rear end will want to kick when going over medium to large bumps (shock resist movement even on medium size bumps)
   2. SOLUTIONS TIP - Decrease compression until harshness is gone To learn what damping can do for your ride, experiment with the compression adjustments and rebound adjustments (if your shock model has them). We suggest you start with compression damping... Turn compression adjuster (blue knob Vanilla RC & Vanilla DH only) to full firm ride your bike for a while and then turn the adjuster to full soft. This will give you an idea what compression damping can do. Likewise do the same with your rebound adjusters..... Feel what fast is..... Feel what slow is
7. Wheel chatters over small bumps during braking or down hills
   1. CAUSES - Too much preload (perhaps because of soft springs) causing suspension to top out; possibly too much compression damping

   2. SOLUTIONS - Reduce preload decrease compression

8. Takes first bump in a series well but harsh over later bumps, poor traction in washboard corners
   1. CAUSES - Too much rebound damping
   2. SOLUTIONS - Reduce rebound damping if adjustable - Nonadjustable - reduce oil weight
9. Front end springs back too quickly after bumps, poor traction in bumpy corners
   1. CAUSES - Not enough rebound damping
   2. SOLUTIONS - Increase rebound damping if adjustable
10. Rear Tuning tips
    1. There are three major adjustments for FOX Racing Shox for Bicycles: Springs / preload, Compression damping, Rebound damping. The spring preload sets the ride height of the bike and determines how much of the total travel will be available for compression and how much will be available for extension. Damping keeps the bicycle from behaving like an old Sacked out Cadillac - i.e., still bouncing 10 seconds after hitting a bump. Compression damping slows the shock when it is being compressed. Rebound damping slows the shock when it is rebounding.
11. Spring preload Tips
    1. Preload is adjusted at the shock body (silver knurled ring) Shaft sag setting too much - Increase preload - maximum two full turns. In many cases you will need to purchase a new spring for correct sag settings. Set

up your bike correctly to keep repair cost down ! Shaft sag setting too little - Reduce preload or use a softer spring.

12. Fox rear shocks spring preload warning

    1. WARNING - If you need more than two turns of preload you will need a higher spring rate. Too much preload will cause the spring to coil bind and in some cases damage to the shock may result. Typical coil bind dam-age - Vanilla RC body end caps cracked or broken and Preload and spring retainers bent or broken... and in some cases bent damper shafts.

13. Not using full travel, feels harsh, poor corning and braking traction

    1. TIPS - Overly stiff spring rate or compression damping, possibly too much preload

14. Shock Damping Adjustment Locations

    1. TIPS - Rebound adjustment (if applicable) is located at the shaft end of rear shock (red knob). Compression adjustment (if applicable) is located at the top of the Vanilla's reservoir (Blue Knob). The Float RL and the Vanilla RL have a blue compression damping lock out lever.

15. Too little Rebound

    1. SYMPTOM - Ride the bike slowly off a curb and if you get after bounce (Boing, Boing, Boing) you will know the setting a little to fast
    2. SOLUTIONS - Increase rebound "gradually" until the wallow is gone and after bounce from curb drop gone

16. Too Much Rebound

    1. SYMPTOM - Ride is harsh, suspension control is limited and traction is lost. Rear end will pack down, forcing the suspension of the bike to skip over bumps instead of following the terrain
    2. SOLUTIONS - Decrease rebound "gradually" until harsh ride is gone and braking traction is regained. This will also keep the rear suspension from packing down

17. Rear shock lack of Compression

    1. SYMPTOM - The rear suspension will feel too active (bounce and wallow excessively) After big jump landings the shock bottoms to easy
    2. SOLUTIONS - Insufficient compression - Increase compression "gradually" until the balance / feel is optimized. You will notice better control over the Bounce and wallow symptoms

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