Spot-On

Prepared for:

Alik Sarkisian
Northwestern University
Evanston, IL 60208

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Submitted by:

Alex Bousky, Weston Kulman, Matt Logan and Conor McGeehan
Section 19, Team 4

Sponsored by:

Design Thinking and Communication
Professors Christopher Naunheimer and Deborah Wood
McCormick School of Engineering and Applied Science
Northwestern University
Evanston, IL 60208

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Executive Summary

The Northwestern University Varsity Diving Team (NUDT) wanted a device that can be used to practice the team's spotting technique, a diving strategy that allows divers to count their rotations during a dive. This would allow the divers to better gauge when to "break out" of their dives and fully extend their bodies, allowing the angle of entry to the pool to be as close to vertical as possible.

We observed divers at the Henry Crown Sports Pavilion and Aquatics Center (SPAC), where NUDT holds its practices, to determine preliminary designs for a device that would accomplish this goal. After speaking to the divers we were able to determine the dimensions within which the machine would need to fit, as well as spacing between the chair and supports that would fit the largest diver's wingspan. Through the use of Computer Aided Design (CAD) and structural analysis, we have determined what materials will best work for this device.

The main feature of our design, Spot-On, is a chair that can rotate 360 degrees along a horizontal axis. When the chair is rotated, this should be comparable to performing maneuvers while diving. The chair has been designed to accommodate the divers who need to tuck their bodies - pulling their arms and legs into their chests - and then extend fully. The device allows divers to practice this on land without putting themselves at risk. Our design is fitted with an emergency foot-pedal brake to stop rotation while keeping the chair still for divers entering the machine. Support straps have also been tested to account for the maximum force that the divers would experience. Lastly, the materials used should under no circumstances fail to support the rotation of the divers after thorough structural analysis.

The main requirements from the client for the design are:

- <u>Dive Simulation:</u> The device should allow the divers to train spotting without impeding on any techniques the divers have developed. Divers must be able to get their legs and shoulders fully tucked, as if they were diving into water in order to fully utilize this device for spotting training.
- <u>Safety:</u> A top priority for us, as well as the client, is safety. This device must be absolutely safe for anybody using it. There are many ethical considerations to be made in regard to the design, and we would not be comfortable submitting a design we do not feel is safe. Furthermore, we are designing this for elite, potentially future Olympic athletes, so their safety is of the utmost importance.
- <u>Permanent Solution:</u> Our device should be a permanent solution to the divers' issue of how to train spotting techniques. Aside from any maintenance the machine would require, this would become an integral part of their training routine and be a permanent addition to the new training area for the NUDT.

Introduction

The technique of spotting is one of the most critical skills for divers. While performing rotations, divers “spot” the water beneath them as they flip in order to determine how many rotations they have done. This allows them to break out of their tucks at the appropriate time by extending their arms and legs (See Appendix B: Background Research).

Our team was asked by Northwestern Diving Coach Alik Sarkisian, to design a solution to a problem encountered by the Northwestern University Varsity Diving Team (NUDT) (See Appendix A: Project Definition). The team has been looking to practice the skill of spotting, but realized that it is difficult to do so while diving into water. It is natural for divers to close their eyes as they are rotating in preparation for contact with the water, and so it can be difficult for divers to focus on both opening their eyes and diving, let alone remaining cognizant of their surroundings as they flip (See Appendix B: Background Research).

Spot-On solves this problem by allowing divers to train their spotting technique on dry land. The device features a harness for the diver to rest in while the coach is in full control of the diver’s rotation. This way, divers need only concern themselves with what they are seeing, and can more efficiently to hone this skill. Spot-On also provides full range of motion, allowing the diver to break out of a tuck after the desired number of rotations.

This report explains the users, requirements and specifications for the requested design, followed by a detailed explanation of the design and its rationale. We conclude with recommendations for testing.

Users and Requirements

Primary Users

Our clients, the NUDT, will be the sole owners and users of our design (See Appendix A: Project Definitions). Diving teams are very competitive and it is therefore the implication that this design will not be marketed or shared with other diving teams. Divers using this device will be both male and female. The coach of the NUDT will also be a user, since he will be operating the crank responsible for rotating the divers.

Requirements

<u>Safety</u>
This device must train the divers without any significant risk. The divers must always be securely fastened into the device, and the movements of the design must simulate regular diving motions. The coach should also be able to operate the crank without any risk of injury (See Appendix A: Project Definitions).

<u>Training</u>
The design must allow the divers the same range of motion they will have in the air and cannot negatively impact the divers' form in any way (See Appendix C: Client Interview Summary). The chair will be designed to allow divers to fully tuck and extend, as they would while performing a normal dive from a high-dive platform into a pool (See Appendix A: Project Definitions).

<u>Structure</u>
The design must be able to hold any member of the NUDT. The device will be made to accommodate any diver up to 300 pounds, and any diver up to 6 feet, 8 inches. The supports will be far enough away from the chair that if a diver with an 82-inch wingspan were to extend his arms they would not come into contact with them. The design must also stay at Northwestern University, in the Henry Crown Sports Pavilion and Aquatics Center (SPAC), but be able to move if needed (See Appendix A: Project Definitions).

<u>Performance</u>
This design must allow for very precise rotations (See Appendix C: Client Interview Summary). It has uninhibited 360 degree rotation along a horizontal axis, and a crank

that allows for very exact rotations of the divers by the operator of the crank (See Appendix A: Project Definitions).

Design Concept and Rationale

Design Description

Our machine is composed of a seat that spins completely around a single, horizontal axis. This seat is interchangeable to accommodate for a wide range of users, and each seat that is used also includes straps and safety measures to ensure the user is secure within it. Once the user is secured in the chair, another person must use the crank on the side to rotate the chair until the training is complete. The chair and axle are suspended by two supports more than capable of sustaining twice the maximum load we expect the design to generate, and all aspects of this design have been implemented to ensure maximum safety.

Figure 1: Final Design

The following section will describe the chair, supports, and turning mechanism in more detail.

Chair
The chair required the longest design process than any other portion of this product. The chair must allow for the divers to fully tuck and extend their legs, just like when they are actually diving. The optimal seat is one that allows for the diver's legs and upper torso to come together, while still providing ample safety and restraints, is the primary challenge. To examine measurements, we primarily dealt with the largest diver, as this in theory would be the most transferrable to the rest of the team until more seats could be designed (See Appendix D: User Observations). The diver’s mid-thigh to upper torso requires the most support, and this would need to be at least 15 inches in length. Through performance testing we determined that a reclined seat position would provide the most comfort to users. A similar chair to our final design is shown below.

Figure 2 (Left): Racing Chair Example Figure 3 (Right): Harness/Restraints Example

This chair utilizes a plastic bucket seat from a racing automobile, which was selected because the chair is designed to stay attached to its mounts even in the event of a head-on collision. While we were not able to find specific numbers for the safety of the chair, it can be safely assumed it is well within the factor of safety for our use. It was also selected because it was prefabricated for use while in a reclined position. The plastic of the seat can also easily be shaped and adjusted for ability of leg movement, or material could be cut from the back if the seat is over-constraining the user. This chair also comes prefabricated with attachment points for a five-point harness. The five-point harness is designed to hold a driver in place effectively even in the event of a rollover, and is therefore perfectly suited for our purposes. The straps are also easy to use and can be adjusted to fit a wide variety of body sizes. This chair is the solution that we recommend at this point, although there are multiple versions of the chair that could be also suited for this task. However, there is no way for us to determine what actually works best without physical user testing of completed designs. Therefore, chairs will be interchangeable so that they can be easily bolted on to the rotating device. Then once the device is completed multiple chair iterations can be manufactured. This allows for a wider range of users to have optimal experience using our device, and if our current solution is not deemed to be the best solution through future user testing, the rest of the device does not need to be altered to make that adjustment.

Supports and Rotating Bar

The supports are designed for maximum stability while withstanding well more than the highest expected weight for a user. The maximum weight of any diver on the team this year was 195 pounds, so we are designing for 225-250 pounds with a factor of safety of 3 or more. The original concept for the supports adopted a tripod theme, but we opted for a platform design that would be more stable. These supports will be made of 4130 steel due to its high-yield strength and weldability and will be 5 feet, 6 inches tall in order to fully suspend even the tallest divers and allow them to feel comfortable without worry of injury while using the device as well as provide room for a padded mat under the surface where the diver will be rotating. The support for the diver will be made out of three-inch outer diameter 1/2-inch wall thickness general-purpose low-carbon steel. This was chosen out of its availability to obtain in small quantities that 4130 could not and still remain relatively inexpensive, as well as its interface with 3-inch bearings, which were the largest diameter that we could purchase before the price jumps exponentially. In our design, the bar that supports the user while training is not continuous but instead splits near the middle where two smaller diameter U-shapes are welded on. Without this feature the center of gravity of the diver would be off-center while they are spinning, causing the diver to experience an uncomfortable and nauseating undulation in the spin. However, by splitting the tube and dropping the seat center the center of gravity becomes centered with the axis of rotation creating a more realistic and safer spin for the diver. This feature can be seen in the figure below.

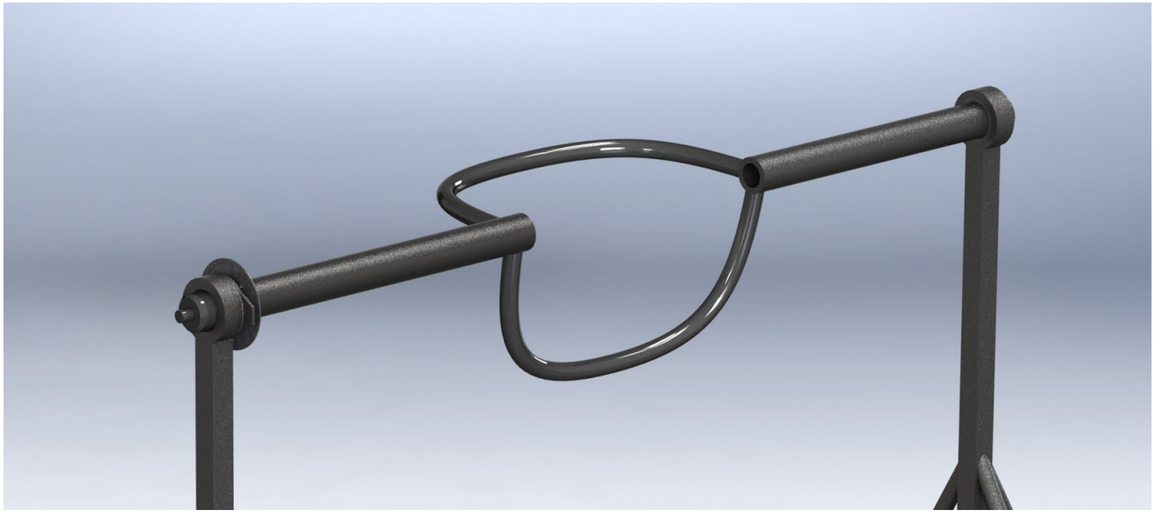

Figure 4: Bent Frame for Center of Gravity for the rotating mass.

Currently this design has a base width of 55 inches, and a center of gravity located at 60 inches off of the ground. With a 200-pound diver in the seat it would take 250 pounds of lateral force at the top of the frame to cause the device to begin to tip, (see Appendix F: Safety Analysis for calculations). While that amount of force is well under working forces, it is recommended for added safety that there are sandbags or weights placed on the feet of the support for an added safety measure. For this reason the feet of the support have been extended out from the center of the machine so that objects such as sandbags or weights can easily be placed on them to hold the frame steady while operation. While permanent weights could have been intentionally added, the device already weighs a considerable amount (400lbs total), and its intent is to be mobile therefore the sandbags are recommended. Another element that was considered but can be solved with the sandbags was increasing the width of the legs to provide more support. This would make it more difficult to tip, however was not pursued because it would give up the mobility of fitting through a 36” doorframe. Once assembled the device can be easily disassembled into three parts: the two frame stands and the bar, by loosening and removing the retaining collars from the shaft with an Allen wrench. This is so that the device can be stored in a much more compact configuration if desired. Additionally the frame should be painted with a metal paint to prevent corrosion and extend the life of the device.

Figure 5: Supports Design

Turning Mechanism

For the device we chose a 30-inch stainless steel sailboat steering wheel. The wheel was chosen because it will be able to easily withstand the 81.4 pounds of force required to rotate a 250-pound diver at 3 revolutions per second. It will also be an easier and a more comfortable interface with the operator than something that could be manufactured in the Ford Design Center. The wheel will have an aftermarket swivel handle bolted to it for better grip and tracking of how many rotations have been completed because the operator's hand does not need to release the wheel to perform a rotation. This will also eliminate risks involving the operator rotating the chair, as it would be much harder to get their hand or arm caught in the rotation, which is a significant issue if choosing a steering wheel style design (See Appendix D: User Observation Guide). In addition, the mechanism will be fitted with a pedal brake system that would serve very similarly to an emergency brake or parking brake in a car. The system will be retrofitted from the disk braking system from a high performance bicycle. That system was chosen because it utilizes a cable to apply pressure to the rotor instead of a hydraulic system in an automobile, which would be overly complex. This system will allow the operator to hold the chair in place while the trainee is secured, and stop the chair from rotating in a quick, yet safe, manner during training or if an issue were to unfold. The design is not meant to utilize instant lock-up of the diver when spinning - as an automobile brake system would be designed for - but instead to decelerate the diver in a constant and controlled manner. This prevents any injury or discomfort that could be caused due to an abrupt stop.

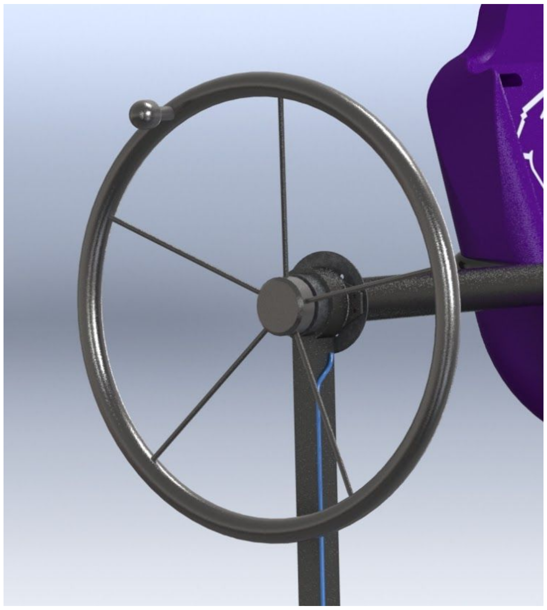

Figure 6 (Left): Wheel Design on Device   Figure 7 (Right): Sailing Wheel Isolated

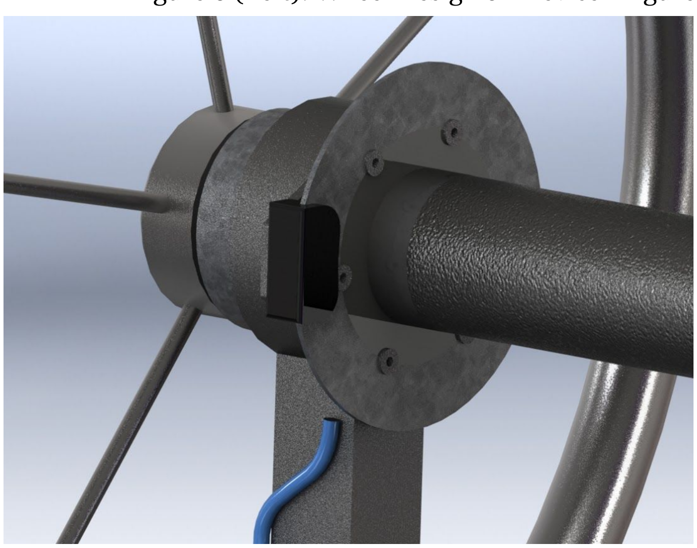

Figure 8 (Left): Tubing/Disc Brake on Axle Figure 9 (Right): Foot Pedal to Operate Brake

Future Development

Our team developed Spot-On to help our users improve their diving spotting. While the design should assist divers with this skill, there are several limitations. The following steps are recommended to further develop the design:

Further Testing

User testing. We developed Spot-On based on observations, interviews, and testing with a small sample size of divers provided to us by our client. With more feedback from other users, this design could be adjusted to be more comfortable, useful and effective. More experts in the field could be consulted to determine how to improve the device as well.

Performance testing. Testing the tensile strength of Spot-On within the expected weight range of divers would help to improve safety (see Appendix F: Safety Analysis). This information could help improve the life of the braking system, as well as the safety of the structure.

Improvements/Maintenance Issues

Currently our design features multiple chairs that can be swapped in and out. While this can make the device more comfortable for users of differing heights and weights, not all body types will fit into the chairs comfortably. A chair that could be adjusted differently for each user would be a better solution to this problem (see Appendix G: Instructions for Use).

Conclusion

To summarize, our design meets the key needs of male and female divers looking to improve their spotting. The design uses a combination of:

- A metal support large and sturdy enough to hold and support a diverse group of divers
- A hand crank for the diving instructor to use to manually rotate the diver in a controlled fashion
- Multiple chair designs so that an array of divers can be comfortable in the device

The Northwestern Diving Team needs a system that is easily adjustable. The alternative chairs provide effortless adjustment for divers of different sizes. The users also require a device that is safe. This sturdy device, with braking system, will not cause any harm to potential users.

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Appendix A: Project Definitions

Project Definition (Version One)

Project Name: Northwestern Varsity Diving Team (NUDT) Spotting Rig
Client: Northwestern Diving Coach: Alik Sarkisian
Team Members: Weston Kulman, Alex Bousky, Matt Logan, and Conor McGeehan
Date: 4/11/2016
Version: One

Mission Statement: To create a device that will improve the diving orientation of the NUDT through adjustable rotational - and possibly revolutionary - simulation.

Project Deliverables: A device that creates a simulation of spotting while outside of the pool during diving practice.

Constraints: The device must be safe enough for a diver to interact with directly, and must not be dangerous to the operator or viewers.

Users/Stakeholders: Users are divers training on the device and coaches operating the device.

Requirements:	Specifications
Purpose/Safety • Device must aid the divers in training without any risk associated	• Divers are always securely equipped within device • Divers are never out of normal training exercises
Structure • Should be able to hold any diver on the team • Should remain at Northwestern University	• Must be able to hold a minimum of 300 lbs. and be comfortable for a human 6-feet. 5-inches. in height.
Performance • Should allow the divers to spin vertically without hindering any	• Should allow for 360 degree rotation on an axis

natural motion of the maneuvers	● Should simulate falling through the air as closely as possible ● Allow for .5 seconds precision on maneuvers

Project Definition (Version Two)

Project Name: Northwestern Varsity Diving Team (NUDT) Spotting Rig
Client: Northwestern Diving Coach: Alik Sarkisian
Team Members: Alex Bousky, Weston Kulman, Matt Logan, and Conor McGeehan
Date: 5/16/2016
Version: Two

Mission Statement: To improve the technique of spotting for the NUDT, which is the ability of divers to see how many rotations they have made. This will allow them to better gauge when to "break out" of their dives and fully extend their bodies, allowing the angle of entry to the pool to be as close to vertical as possible.

Project Deliverables:

- Complete design plans for a device that recreates spinning while diving in order to help the divers with spotting.
- Cost analysis of this design that would help our client implement it as he sees fit
- Both dynamic and static structural analyses of the design to ensure safety standards are met, as well as how to meet these standards.

Constraints: The device must be a non-permanent fixture that is safe enough for a diver to interact with directly while training spotting, and must not be dangerous to the operator or viewers.

Users/Stakeholders: Users are divers training on the device and coaches operating the device.

Requirements:	Specifications
Purpose/Safety ● Device must aid the divers in	● Divers are always securely

training without any risk associated	equipped within device ● Divers are never out of normal training exercises
Training ● The device must not influence training negatively, nor can it excessively restrict the divers natural motions	● Chair will be designed to allow divers to tuck and extend fully, as if they were performing a dive over water.
Structure ● Should be able to hold any diver on the team ● Should remain at Northwestern University	● Must be able to hold a minimum of 300 lbs. and be comfortable for a human 6-feet 5-inches. in height. ● Chair will be far enough from supports to accommodate a diver with wingspan of 80 inches.
Performance ● Should allow the divers to spin vertically without hindering any natural motion of the maneuvers ● Should allow for precise rotations	● Should allow for 360 degree rotation on a horizontal axis ● Should simulate falling through the air as closely as possible ● Allow for .5 sec precision on maneuvers ● Wheel will be used to turn the chair/divers, and this wheel will have pegs or marking to provide optimal measuring of the rotations completed.

Project Definition (Final Version)

Project Name: Spot-On
Client: Northwestern Diving Coach: Alik Sarkisian
Team Members: Alex Bousky, Weston Kulman, Matt Logan, and Conor McGeehan
Date: 5/24/2016
Version: Final

Mission Statement: To improve the technique of spotting for the Northwestern University Diving Team, which is the ability of divers to see how many rotations they have made. This will allow them to better gauge when to “break out” of their dives and fully extend their bodies, allowing the angle of entry to the pool to be as close to vertical as possible

Project Deliverables:

- Complete design plans for a device that recreates spinning while diving in order to help the divers with spotting.
- Cost analysis of this design that would help our client implement it as he sees fit
- Both dynamic and static structural analyses of the design to ensure safety standards are met, as well as how to meet these standards.

Constraints: The device must be a non-permanent fixture that is safe enough for a diver to interact with directly while training spotting, and must not be dangerous to the operator or viewers.

Users/Stakeholders: Users are divers training on the device and coaches operating the device.

Requirements:	Specifications
Purpose/Safety ● Device must aid the divers in training without any risk associated	● Divers are always securely equipped within device ● Divers are never out of normal training exercises
Training ● The device must not influence training negatively, nor can it excessively restrict the divers natural motions	● Chair will be designed to allow divers to tuck and extend fully, as if they were performing a dive over water.
Structure ● Should be able to hold any diver on the team ● Should remain at Northwestern University	● Must be able to hold a minimum of 300 lbs. and be comfortable for a human 6-feet. 5-inches. in height. ● Chair will be far enough from supports to accommodate a diver with wingspan of 8- inches.

Performance • Should allow the divers to spin vertically without hindering any natural motion of the maneuvers • Should allow for precise rotations	• Should allow for 360 degree rotation on a horizontal axis • Should simulate falling through the air as closely as possible • Allow for .5 seconds precision on maneuvers • Wheel will be used to turn the chair/divers, and this wheel will have pegs or marking to provide optimal measuring of the rotations completed.

Appendix B: Background Research Summary

Introduction
We conducted some background research after seeing the project description our client, Alik Sarkisian, the coach of the Northwestern University Diving Team (NUDT), provided to gain a better understanding of our project, which is to create a device to assist divers in the practicing of their spotting technique during dives. In particular, we researched: (1) basic information on spotting, (2) the users, and (3) current products used to practice diving spotting.

Diving Spotting
Spotting is the technique of looking for visual stimuli while diving. It is used to recognize the water while rotating, so that divers can more accurately determine where they are in their dive and the appropriate time to "kick out" of their dive (extending their arms and legs in preparation for entering the water). This technique is typically practiced first on land, and then translated into diving over water. Diving coaches typically utilize a diving harness and spotting rigs to train this, but our client wants to streamline this process to make training easier and more efficient. Northwestern Diving currently using these conventional methods of pulley systems to simulate diving, and we think we can develop a new design, or modify existing technology to provide a better training method.

Figure 10: Snapshot of NUDT Diver Demonstrating a Maneuver

This is an example of a moment when the divers would be using spotting, to see when the water is passing while rotation.

Previous Technology Search

A search using the United States Patent Office Search Engine provided no existing technologies using key-words such as diving and spotting, gymnast assist, flip assist, swimming and diving, diving machine, etc. Nothing of note was found that would interfere with our design and manufacturing of a diving flip training device. The only existing technologies that we have heard of or seen are owned privately. We believe the University of Indiana has one, as well as Germany's Olympic diving team. We have seen a video of an Olympic diver from Britain using the machine in Germany, but nothing more that would indicate there is existing technology that would interfere with our design.

Appendix C: Client Interview Summary

We had our initial interview with our client, Alik Sarkisian, the Northwestern University Diving Coach, on Tuesday, April 5th, 2016 at 1:00 p.m., in the Henry Crown Sports Pavilion and Aquatics Center at Northwestern University. The entire Northwestern Diving Team was in attendance. The purpose of the meeting was to learn more about the coach's desire to improve the team's ability to practice the technique of spotting on land. This appendix summarizes what we learned about the design problem, requirements, user and current equipment.

Problems

Our client emphasized the following problems that divers have while attempting to spot:

- When learning to spot in water, it is natural for divers to close their eyes and therefore makes it harder to learn
- When diving spotting in the pool, the coach has no control over the rotation

Requirements

Our client identified these requirements for the design

- Safety
- Ease of use
- Comfort
  - The device should be comfortable for a wide variety of Northwestern Divers to use
- Safety
  - The device will be a complex machine, which inherently requires strict safety standards
  - Any divers using the device must be safe while rotating in the device
  - The coach must be safe while controlling the rotation of the diver
  - The device must be able to accommodate divers weighing upwards of 200 pounds

Users

- The users of this device will be the Northwestern Diving Team and its coach
- The divers will be college students with a maximum weight of 250 pounds
- There are about 10 members of the Diving Team each year

The interview provided crucial information for understanding the problem, users and client requirements.

Appendix D: User Testing Guide

We will use the following testing guide with the users as they perform tasks with our two wooden, small-scale mockups. These mockups differ in design being that one is what the client asked for, a free standing device that spins the diver a precise number of times, while the other utilizes already existing equipment in the diving training room.

Tasks involve performing different maneuvers with each mockup and comparing their effectiveness in aiding the performance of said maneuvers.

Our goals are to learn what mockup would best aid in the training of spotting for divers, and if there is a difference between the two in the eyes of the diver.

Start Time:

Introduction (for users): Our project is to design a device that will help the Northwestern University Diving Team with developing the skill of spotting during dives. We will have users try the device for a certain period of time and see if the design would help aid in training The mockups you will be using are not intended to simulate the final product in terms of materials, appearance, etc., but your interaction with them will provide us with valuable information so that we can move forward with our design. Please feel free to ask questions or comment at any time.

Overall Questions about each design:

- What do you like about each design?
- What do you dislike about each design?
- Which design would you prefer to use for practice?

Chairs:

1. Full Chair with Straps- **Pros:** extremely safe, fully secure with no chance for malfunction or failure, quite comfortable. **Cons:** too stiff, restricts mobility throughout the body, not in line with design goals. **User Reaction:** The user places a primacy on movement and full range of motion within the harness making this fixed position less than ideal.

2. 5-pt Harness- **Pros:** Also quite safe and secure, frees the legs of the individual using the device giving more complete range of motion. **Cons:** Still restricts the movement of the upper body causing an unnatural motion in the dive and hanging restraints can be quite uncomfortable. **User Reaction:** Divers did not like the idea of hanging restraints and lack of mobility in the upper body would be too severe for it to be an effective design.
3. Cup Seat with Lap Restraint- **Pros:** Full range of motion both in the user's legs and upper body, comfortable. **Cons:** With less straps the design becomes much more complicated to ensure complete safety while remaining the most effective design. **User Reaction:** Very positive, this received the most support and will receive the most attention moving forward.

Training Belt with Lift System:

1. What do you think about an attachment to the training belt?

An attachment could work to rotate, but we would need to work within the existing space.

2. What do you like about this idea?

   It could be safe and helpful if executed properly, but I don't know what to do to help with the design of the attachment

3. What do you dislike?

   We think that this is an okay idea, but this is technology that may not need to be adjusted. The belt works pretty well already, and the chair would be more a more unique addition to the training regimen we have in place.

Appendix E: Safety Analysis

Moment Calculation for Tipping:

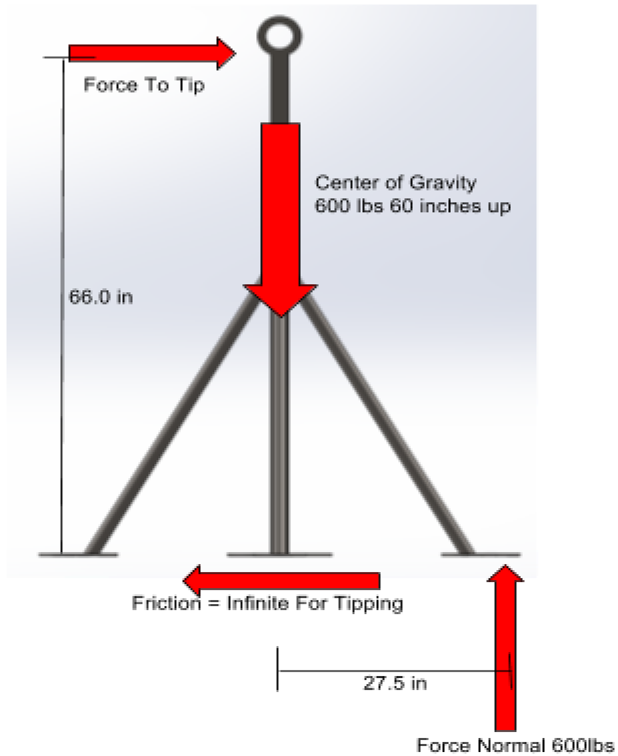


Figure 11: Diagram Outlining Forces Required to Tip over Device

$$Fnormal * 27.5 = 66 * Ftip$$
$$(600 * 27.5)/66 = Ftip = 250lbs$$

Torque Calculation for 30 inch Handle:

At 3 rps

$$Inertia = 1/2\, m\, r^2$$
$$110\, kg * .35^2\, m * 1/2 = 6.737\, kg\, m^2$$
$$alpha = \Delta w/\Delta t$$
$$6pi\ rad/sec/sec = 10.84 r/s^2$$
$$6.737 * 18.84/.35 = 362.67\ newtons$$

=81.55 lbs of force at the handle
Changing the rotation to 2 rps gives 54.37 lbs of force
(Both well within the means of exertion of an average human)

Bending of the Bar:

Due to the complexity of this calculation this was done on the website calculator http://www.engineering.com/calculators/beams.htm using the inputs of length 80 inches, diameter 3 inches, wall thickness ½ inches, and force 250-pounds. To give the result of a deflection of .44 inches and a stress of 9402.38 psi. The stress of this is well below the yield stress of the 1018 steel being used, which is 45,000 psi. It is also very safe in terms of cyclical stress having steel reach its endurance limit of 30,000 psi after 10^6 cycles. Meaning this device can be used for an extended period of time without worry of excess fatigue. See Graph Below.

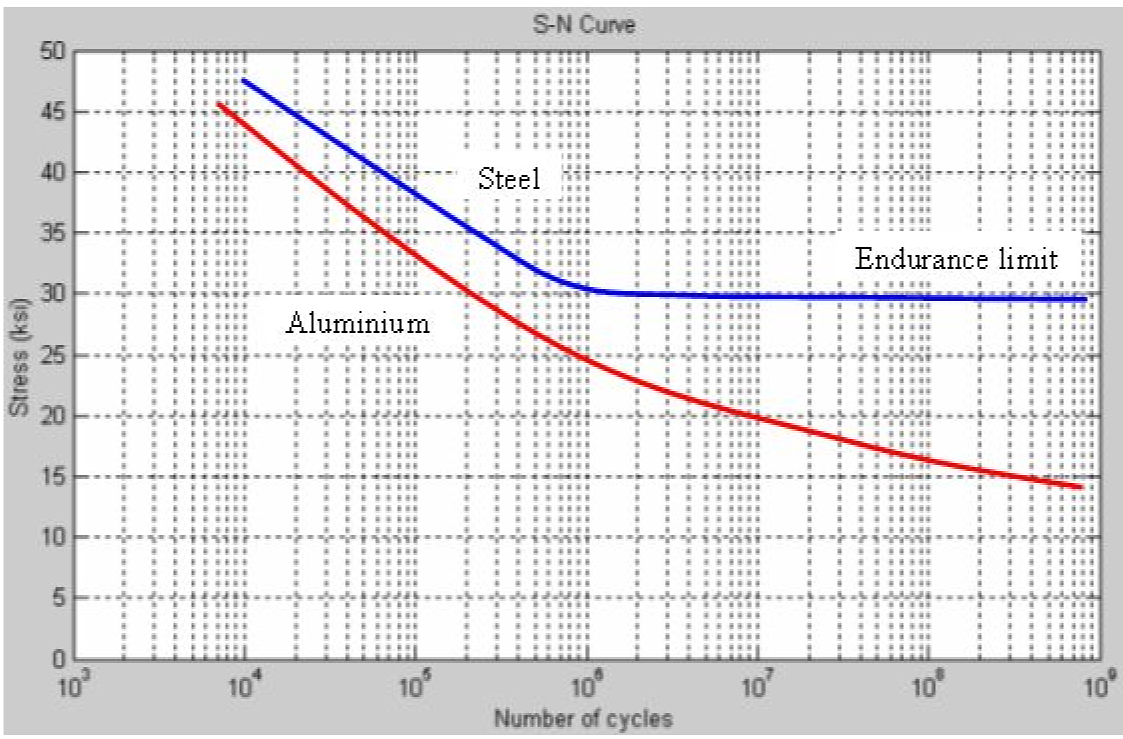


Figure 11: Graph of cyclical stress of general-purpose steel and aluminum
Source: https://upload.wikimedia.org/wikipedia/commons/3/30/S-N_curves.PNG

Finite Element Analysis:

A method called finite element analysis was used in the design of this system. Its results however were not used to design the device as much as support the safety of the machine. For example when run for the support with a force of 150-pounds on the bearing surface (half of the total), the max stress of the support was only 200 psi when the yield strength for the 4130 steel in its construction is well above 66,000. This can be seen in the figure below.

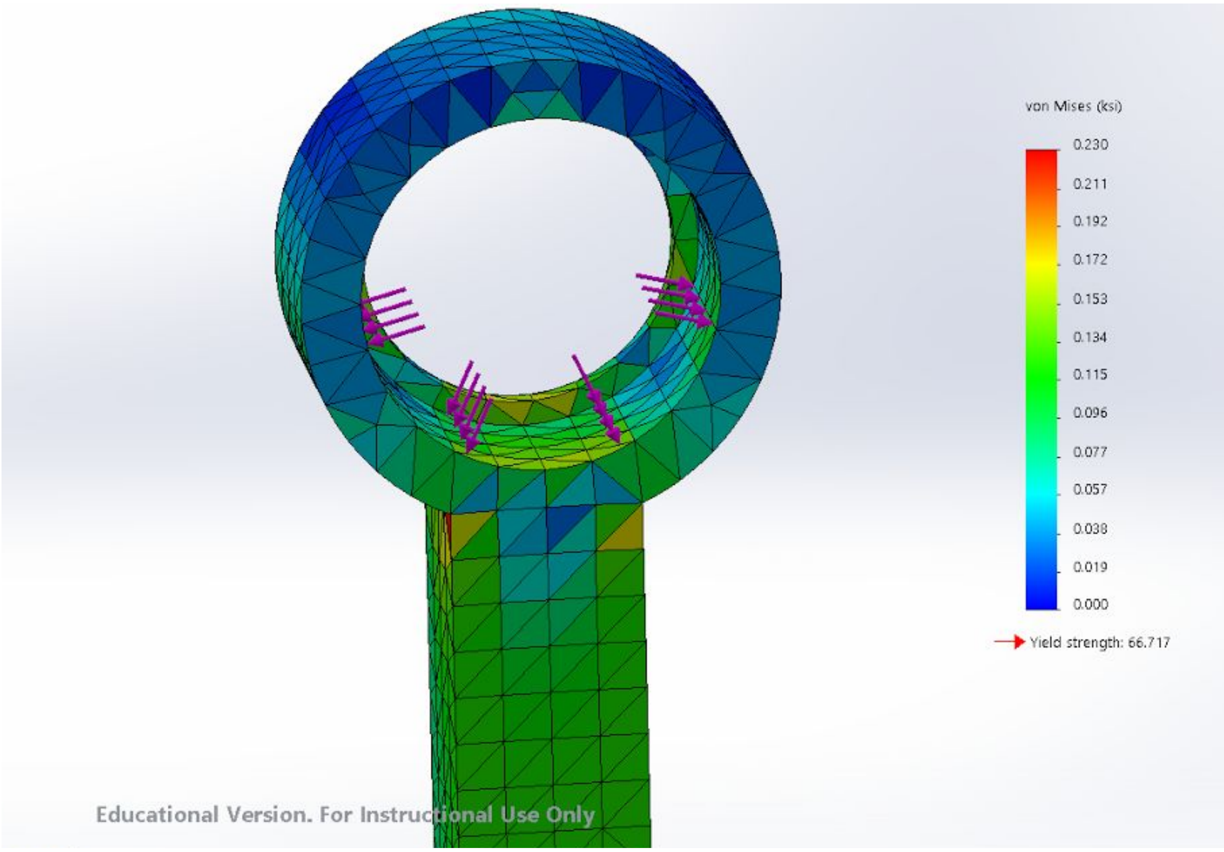


Figure 12: FEA Stress analysis of the support. (The colors coincide with the scale on the right of the photo, Red being highest stress at 230 psi and blue meaning 0 stress)

Appendix F: Instructions for Use

These are the instructions for how to use our device to develop spotting techniques:

1. Assess the device for safety before use. This should entail checking for loose screws, ensuring the device is mounted securely, and determining if the straps are worn in any way.
2. Have the coach who is rotating the diver firmly grasp the turning mechanism and hold their foot on the brake pedal to restrict any rotation of the chair.
3. Using a step stool, have the diver step into the chair.
4. A third user (diver or coach) should strap the diver in, checking to make sure they are secure, and then remove the step stool.
5. Depending on training methods, the coach could alert the diver how many rotations to expect, or begin rotating the diver and have the diver announce the number of rotations once the "maneuver" is complete.
6. Rotations should be performed over a blue mat or surface to simulate the color of water, as this will most closely translate to real diving.
7. Once the "maneuver" is complete, the user operating the turning mechanism should hold the chair firmly in place, and hold the brake to prevent motion.
8. Step stool should be replaced, and the third user should aid the diver in removing the restraints.
9. Warning: The brake is not in place to completely stop motion instantaneously, it is a mechanism aimed to help slow rotations once training is complete. The user must always have a firm grip on the turning mechanism to avoid safety.
10. Maintenance Concerns: painting and re-painting of the device should occur whenever paint begins to chip. Keeping the steel from rusting is imperative to the structural integrity of the device.
11. Maintenance Concerns: If rotary motion becomes harder over time, the shaft of the device should be lubricated regularly. This will protect the device and provide easier use for the divers and coaches involved.

This process should be completed repeatedly for each member of the team, or each member that is training this technique on a given day.

Appendix G: Bill of Materials

Item	Quantity	Total Item Cost	Labor Item	Time (hrs.)	Cost @ $9.00
LC Steel Tubing: 3 inch OD, 2 inch ID, ½ inch wall thickness http://www.mcmaster.com/#7767t91/=12mhjss	1 x 6 ft.	$314.92	**Cutting**	2	$18.00
Easy to Weld 4130 Alloy Steel Round Tube: 1.5 inch OD, .188 inch wall thickness http://www.mcmaster.com/#89955k501/=12mh2q0	5 x 6 ft.	$555.20	**Welding**	4	$36.00
LC Steel Square Tube: 2 inch x 2 inch, ¼ inch wall thickness http://www.mcmaster.com/#6527k614/=12mh37c	2 x 6 ft.	$69.82	**Assembly**	2	$18.00
Sunlight Brake Cable w/ housing: at least 2000 mm http://www.illinois-cycle.com/product/sunlite-brake-cable-with-housing-209809-1.htm	1	$6.76	**Truing**	1	$9.00
McGill MR48 CAGEROL Bearing, Inch, 3 inch ID, 3-¾ inch OD, 1-¾ inch Width, Max RPM, 63400 lbs. Static Load Capacity, 30300 lbs Dynamic Load Capacity	2	$81.90	**Manufacturing**	40	$360

http://www.amazon.com/dp/B006KT2F6M/ref=nav_timeline_asin?_encoding=UTF8&psc=1					
Stainless Steel Sailboat Wheel 30 inch http://marinesteeringwheels.com/shop/sailboat/stainless-steel-sailboat-wheel-6-spoke/	1 (30 inch d)	$245.03		Total hours	Total Cost
Whitecap Stainless Steel Speed Knob http://www.amazon.com/Whitecap-Stainless-Steel-Speed-Knob/dp/B000221GJA/ref=sr_1_29?ie=UTF8&qid=1464483411&sr=8-29&keywords=destroyer+steering+wheel	1	$40.95		49	$441.00
Set Screw Shaft Collar: for 3 inch Diameter (black oxide steel) http://www.mcmaster.com/#9414t52/=12mh6lp	3	$81.69			
LC Steel Square Tube: 1 inch x 1 inch, .12 inch wall thickness http://www.mcmaster.com/#6527k364/=12mh6wq	1 ft	$7.97			
LC Steel Rod: 5 inch Diameter 1 inch Length http://www.mcmaster.com/#7786t64/=12mh9et	1	$21.98			
LC Steel Tubing: 2 inch OD, 1.5 inch ID, .25 inch wall thickness, 24 inch leg length @ 90 degree angle	4	$670.16			

http://www.mcmaster.com/#7767t984/=12mhkl6					
Summit Racing Poly Performance Seat Sum-G1100 http://www.summitracing.com/parts/sum-g1100	1	$34.97			
TRP Spyre Road Disc Brake http://www.illinois-cycle.com/product/trp-spyre-road-disc-brake-188660-1.htm	1	$108.95			
Shimano SLX 203mm 6-bolt Disc Rotor http://www.wiggle.com/shimano-slx-203mm-6-bolt-disc-rotor/	1	$18.99			
Racequip 5pt Latch and Link HArness http://www.saferacer.com/racequip-5pt-latch-link-harness?gclid=CJ2IsZ_ehMoCFQ-oaQodCCcOwQ	1	$69.95			
LC Steel Rectangular Bar: ¼ inch thick, 5 inch length http://www.mcmaster.com/#8910k591/=12nq73k	5 inch x 3 ft	$50.41			
		Total Parts Cost			**Parts + min. wage labor**
		$2,379.65			$2820.65

Appendix H: Instructions for Construction

In order to construct the Spot-On you must have skills in CNC machining, welding and lathe operations. Before beginning, gather all of the materials you will need for construction (Appendix H: Bill of Materials). Dimensions for all parts and assemblies are found in Appendix J: Drawings.

Stand:

To begin, cut the 2 x 2 square steel tubing to length of 5-foot, 6-inches. Cope the end of the tube to a 5-inch diameter. Then cut each one of the leg tubes to size with the correct angles for them to be welded on to the central pole. After this, waterjet out the central and leg foot pieces. Then weld each foot onto its respective leg, and the legs to the central square tube, making sure that each weld has full penetration. Once you have this assembled, to create the bearing housing cut down the 5-inch round stock to a 2-inch long piece, then using a CNC mill, cut out the bearing surface and the through hole. Once this is completed, weld the bearing housing to the coped surface at the top of the coped 2-inch square tube with the bearing surface pointing toward the middle of the machine. The bearing can now be press fit into the 3.75-inch hole. That process is now repeated a second time identically.

Bar:

First, cut down the 3-inch outer diameter ½-inch wall tube down to 28.5-inch lengths. Once the seat is selected, measure its dimensions and design an attachment that goes from the bent seat tubes to the desired seat (the bar is easily modular to multiple seats). Once this is done the bent seat tubes can be welded onto the 3-inch O.D. tubes. Then measure the dimension of the interface and hole pattern of the brake rotor that was purchased, making sure that the one that is selected has a inner diameter over 4 inches in diameter. Next, adjust the rotor plug to fit the dimensions of the rotor selected, both in diameter of the interface and thickness (these are marked on the drawing). Then manufacture the rotor plug using a manual lathe out of the solid 5-inch diameter stock. Finally, weld the rotor plug into the left side of the 3-inch diameter tubing and bolt on the rotor to the rotor plug.

Brake System:

The brake system will be using a bicycle disk caliper. A bracket for the attachment of the caliper to the bearing housing is necessary because the hole pattern is not known until the caliper is purchased and measured. Once this is designed it is welded to the bearing housing. The brake line will then be run from the caliper down the 2x2 tube and down the center leg to the pedal. Cut the line to length and weld small retaining tabs onto the frame in order to hold the line casing to the device. Manufacture the pedal by cutting a 1-inch tube to 4-inches in length, drilling a 0.375-inch hole on one end and welding the foot placement point to the other end. A method for tensioning and attaching the pedal cable will also have to be designed once parts arrive. The pedal is mounted by welding the two pedal mounts to the left-middle foot 1.25 inches apart. Then the pedal will be mounted with a 0.375-inch bolt to rotate about it.

Seat:

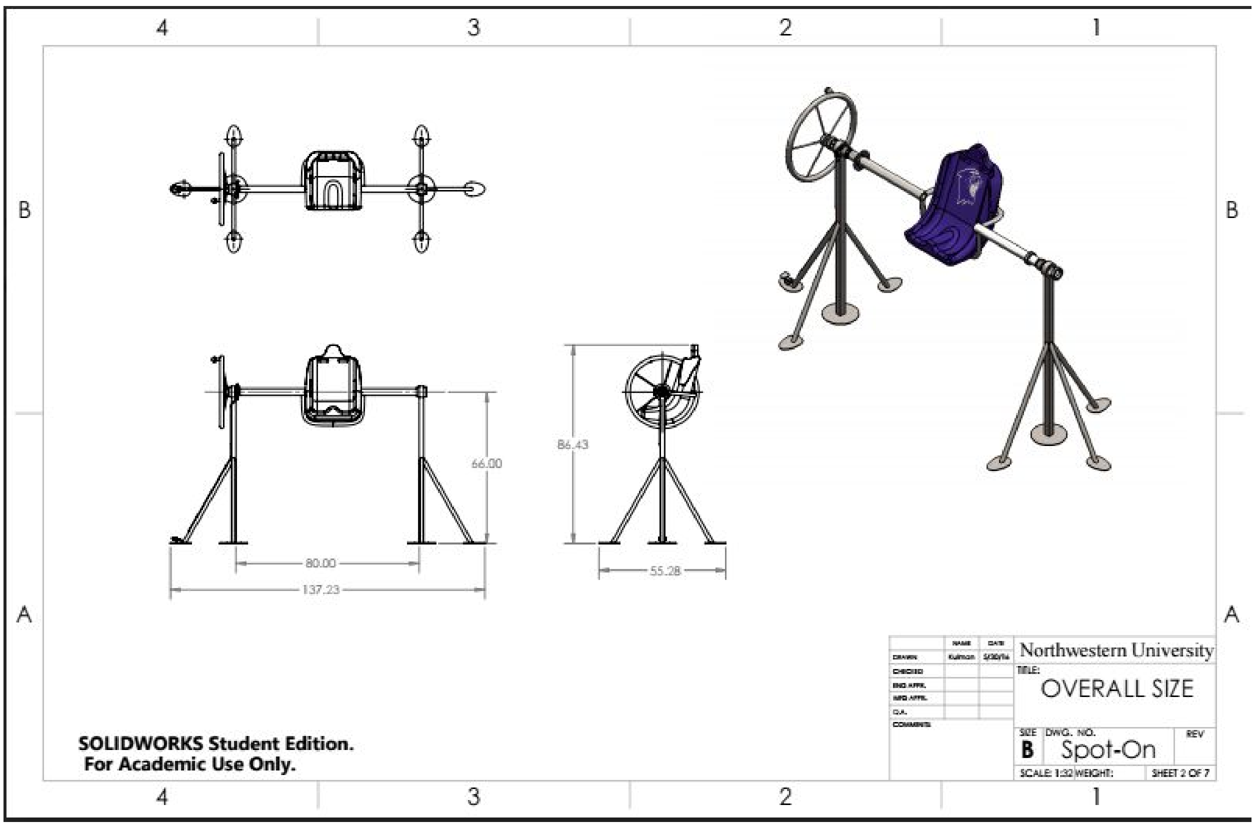
The seat should be purchased initially. This seat will need to be modified to be use with the device. It will also have to be interfaced with the five-point harness and this attachment will have to be designed and mounted once the parts are purchased. The current seat is designed to have the harness mounted to it so these modifications will most likely be minimal.

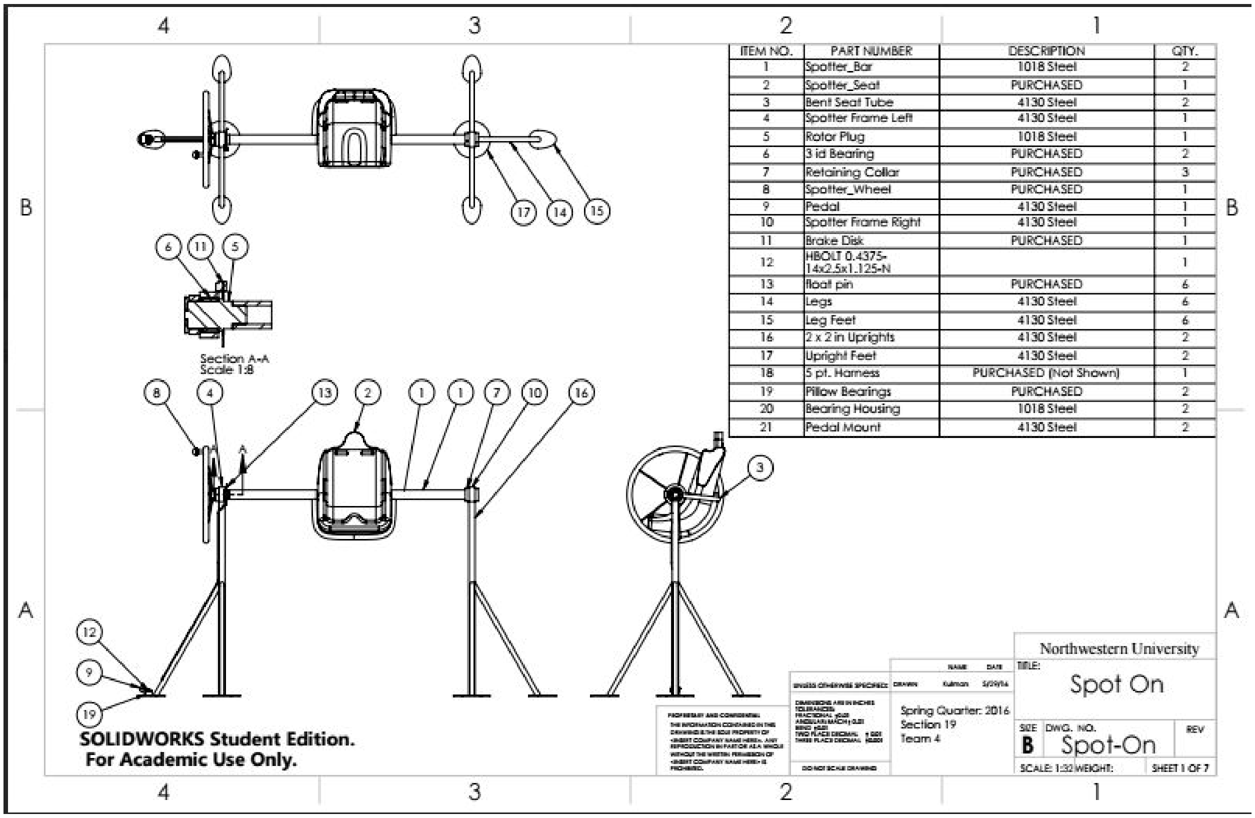
Assembly:

Once each of the previous sections are complete the Spot-On device can be assembled. This is done by standing up the two supports 80 inches away from each other. The bar can then be slid into the bearings at the top of the supports; the side with the rotor plug and the brake rotor should be slid into the side with the caliper attachment point. Before sliding the right side in place a retaining collar on the three inch tube so that it will be on the inside of the bearing and tighten it down 3.125 inches away from the end. Note that the caliper cannot be attached before the bar is installed. Once both sides of the tube are within their bearings, make sure that the they are slid completely on and touching the rotor plug on the left side and the retaining collar on the right. The other two retaining collars can be put on and tightened, however there should still be some lateral play in the bar so that spinning is still easily possible (check that it can still spin before tightening down completely). The caliper can now be installed around the brake rotor by bolting it on at the designated rotor attachment point. The wheel can now be installed and tightened on the one inch shaft of the rotor plug that is still protruding out from the retaining collar, and the crank handle should be bolted on to the outer diameter of the handle at 90 degrees clockwise from vertical when the seat is in the vertical position. Lubrication should then be added to every part where there is some sort of rotation or movement except the brake rotor. This is so that the parts do not seize and become corroded. All exposed parts that do not contact the bearings should then be painted with a metal spray paint, this is to protect from corrosion of the welds. After a safety test and once over that all components are installed, the Spot-On device is now ready to be used.

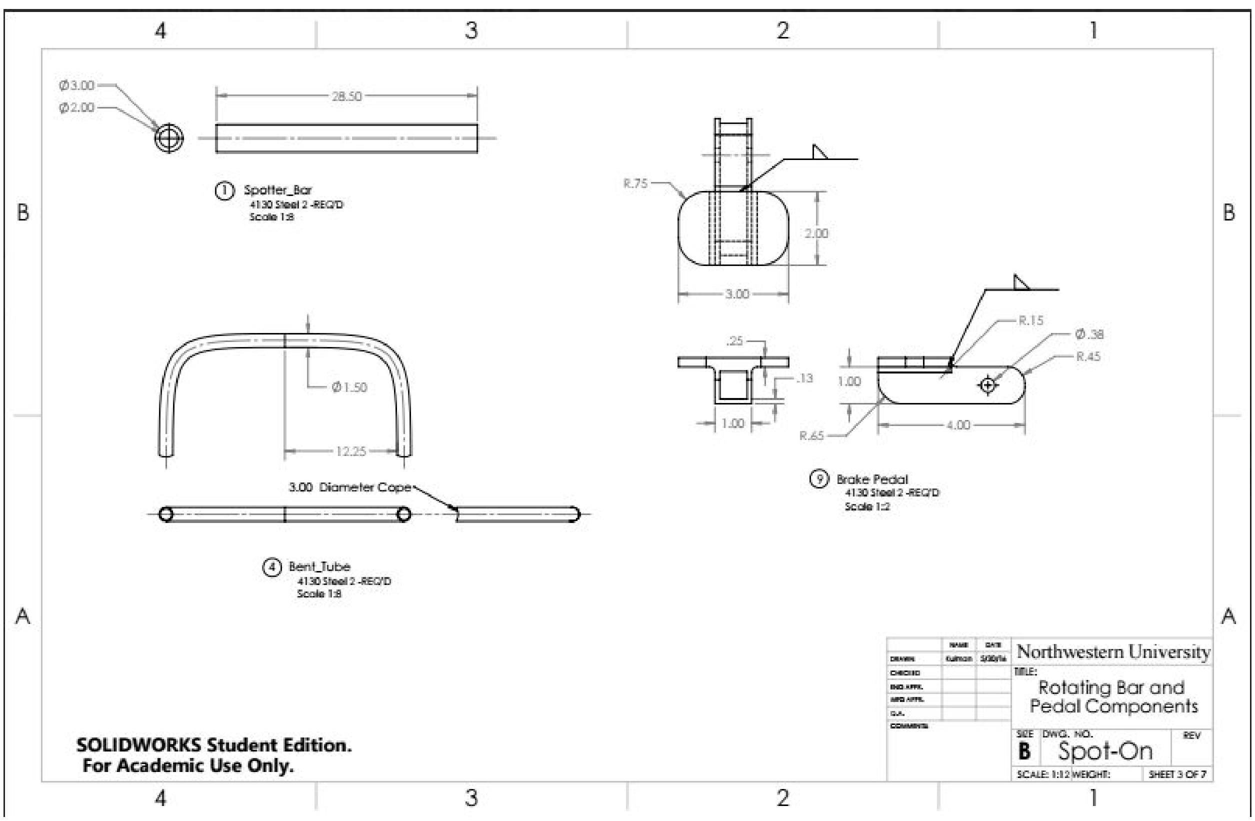
Appendix I: Drawings

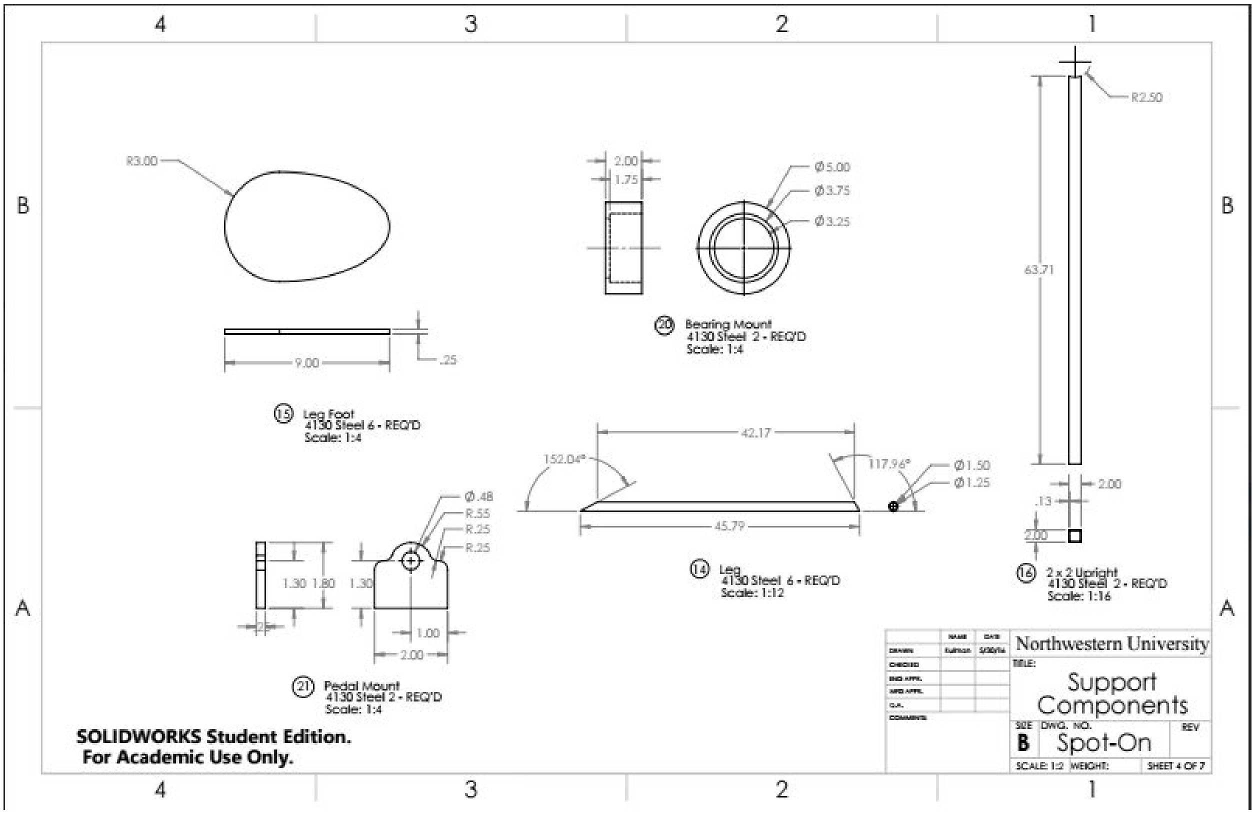
These are the drawings of the device generated by CAD that will be delivered to the client as part of the complete design.





ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Spotter_Bar	1018 Steel	2
2	Spotter_Seat	PURCHASED	1
3	Bent Seat Tube	4130 Steel	2
4	Spotter Frame Left	4130 Steel	1
5	Rotor Plug	1018 Steel	1
6	3 id Bearing	PURCHASED	2
7	Retaining Collar	PURCHASED	3
8	Spotter_Wheel	PURCHASED	1
9	Pedal	4130 Steel	1
10	Spotter Frame Right	4130 Steel	1
11	Brake Disk	PURCHASED	1
12	HBOLT 0.4375-14x2.5x1.125-N		1
13	float pin	PURCHASED	6
14	Legs	4130 Steel	6
15	Leg Feet	4130 Steel	6
16	2 x 2 in Uprights	4130 Steel	2
17	Upright Feet	4130 Steel	2
18	5 pt. Harness	PURCHASED (Not Shown)	1
19	Pillow Bearings	PURCHASED	2
20	Bearing Housing	1018 Steel	2
21	Pedal Mount	4130 Steel	2





R3.00
9.00
.25
15 Leg Foot
4130 Steel 6 - REQ'D
Scale: 1:4
2.00
1.75
Ø5.00
Ø3.75
Ø3.25
20 Bearing Mount
4130 Steel 2 - REQ'D
Scale: 1:4
42.17
152.04°
117.96°
Ø1.50
Ø1.25
45.79
14 Leg
4130 Steel 6 - REQ'D
Scale: 1:12
Ø.48
R.55
R.25
R.25
1.30
1.80
1.30
1.00
2.00
21 Pedal Mount
4130 Steel 2 - REQ'D
Scale: 1:4
R2.50
63.71
2.00
.13
2.00
16 2 x 2 Upright
4130 Steel 2 - REQ'D
Scale: 1:16
Northwestern University
TITLE:
Support Components
SIZE DWG. NO. REV
B Spot-On
SCALE: 1:2 WEIGHT: SHEET 4 OF 7
SOLIDWORKS Student Edition.
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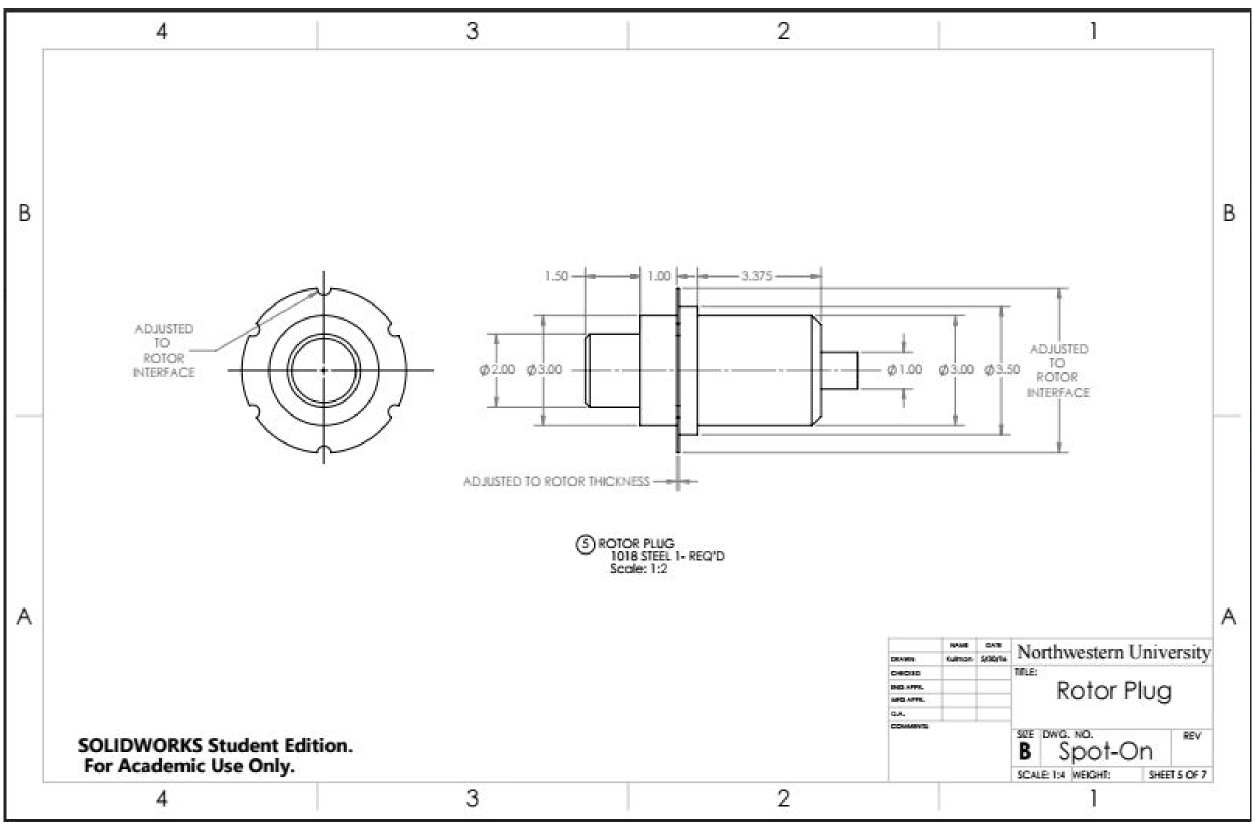

ADJUSTED TO ROTOR INTERFACE
1.50
1.00
3.375
Ø2.00
Ø3.00
Ø1.00
Ø3.00
Ø3.50
ADJUSTED TO ROTOR INTERFACE
ADJUSTED TO ROTOR THICKNESS
5 ROTOR PLUG
1018 STEEL 1- REQ'D
Scale: 1:2
Northwestern University
TITLE:
Rotor Plug
SIZE DWG. NO. REV
B Spot-On
SCALE: 1:4 WEIGHT: SHEET 5 OF 7
SOLIDWORKS Student Edition.
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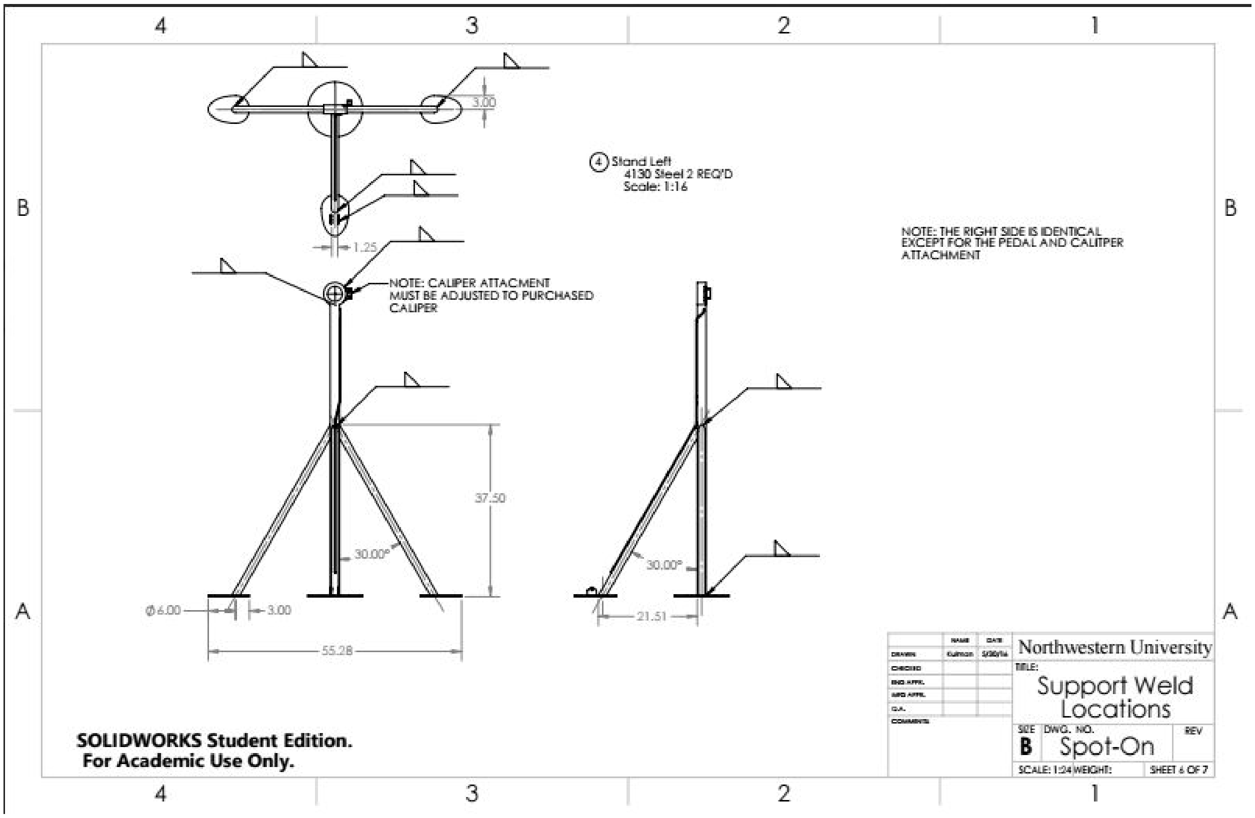

3.00
4 Stand Left
4130 Steel 2 REQ'D
Scale: 1:16
NOTE: THE RIGHT SIDE IS IDENTICAL EXCEPT FOR THE PEDAL AND CALITPER ATTACHMENT
1.25
NOTE: CALIPER ATTACMENT MUST BE ADJUSTED TO PURCHASED CALIPER
37.50
30.00°
30.00°
Ø6.00
3.00
55.28
21.51
Northwestern University
TITLE:
Support Weld Locations
SIZE DWG. NO. REV
B Spot-On
SCALE: 1:24 WEIGHT: SHEET 6 OF 7
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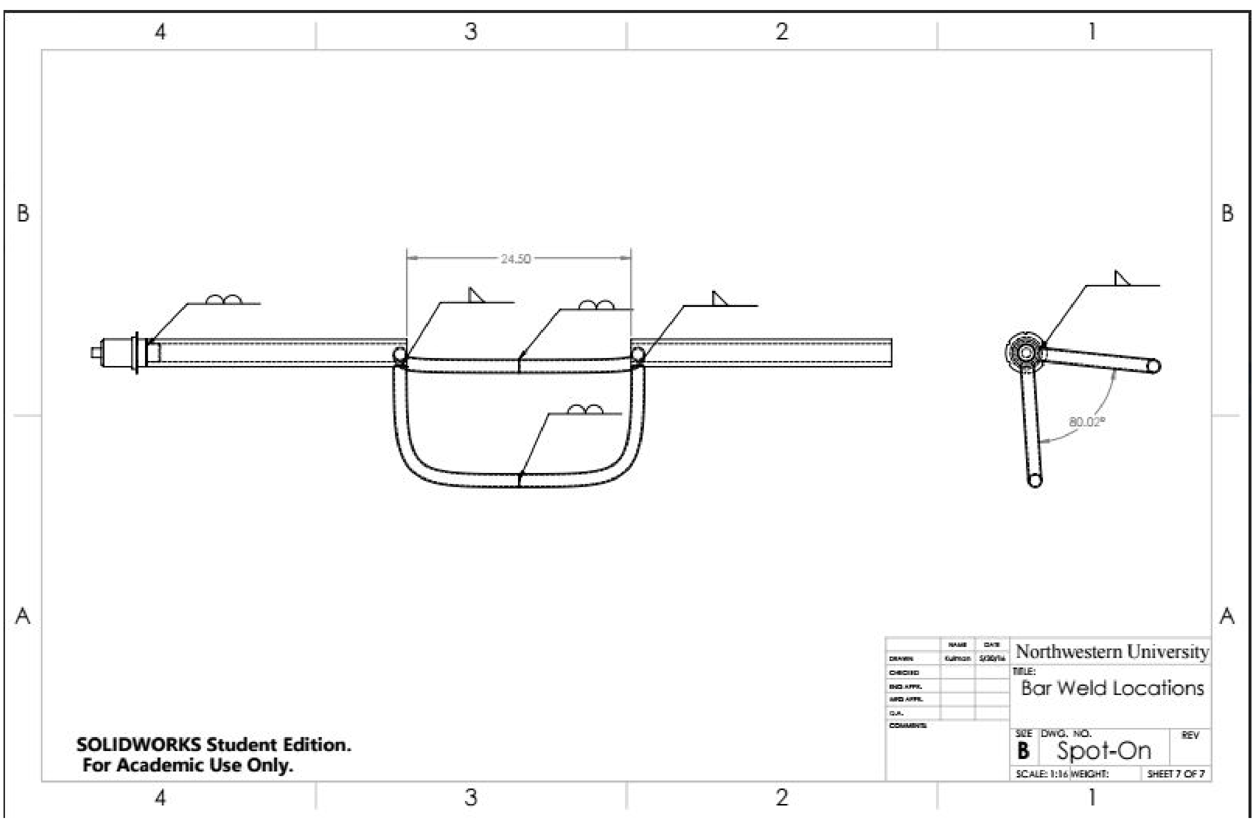

24.50
80.02°
Northwestern University
TITLE:
Bar Weld Locations
SIZE DWG. NO. REV
B Spot-On
SCALE: 1:16 WEIGHT: SHEET 7 OF 7
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