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SONAR CLASS ADAPTIVE SAILING JIB TRANSFER SYSTEM

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ABSTRACT

The adaptive sailing jib transfer system is a device that enables people with lower limb disabilities to actively participate in the sport of sailing. The device provides a seat and platform for the user to sit upon, and provides a mechanism of transport from one side of the boat to the other without requiring any leg usage. When the user releases the brake, the device swings from its locked position on port or starboard to the opposite side, and automatically locks into position again. This enables the user to perform the duties of a jib trimmer crewmember on a Sonar class of sailboat. In 2013, a prior RIT Senior Design group had tackled this problem, but this iteration provides a new and improved solution to this challenge.

NOMENCLATURE

Jib – Triangular headsail on a boat. On a two-sail boat, typically the smaller of the two and closer to bow.
Jib trimmer – The crewmember who controls the jib
Lines – Ropes that control various sails or equipment
Port – The "left" side of the boat as viewed from inside, looking towards bow (opposite of starboard)
Sonar – A 23' sailboat. One of the premier boat classes for Paralympic racing.
Starboard – The "right" side of the boat as viewed from inside, looking towards bow (opposite of port)

INTRODUCTION

Sailing is an activity that promotes lifelong wellness and a sense of freedom not easily experienced on land. People with limited or no leg mobility who would like to participate in this activity have additional challenges when faced with the need to move about the boat. A crewmember in the role of a jib trimmer plays a pivotal role in the sailing activity. He is not only responsible for the adjusting the tautness of the jib sail, but he is also responsible for being the 'eyes' of the boat for the entire crew, as well as traversing the width of the boat in order to provide crucial weight distribution. For a person with limited or no leg mobility, these tasks become severely taxing, or even impossible, without the use of an assistive device. This undergraduate engineering capstone project focuses on designing a jib transfer system to address these challenges.

The jib transfer system is an assistive device that enables a jib trimmer to move transversely across the width of the sailboat without the use of their legs and with only limited use of their core muscles. A jib transfer bench was created in Rochester Institute of Technology's Spring 2013 term that is heavy, expensive, labor-intensive to assemble, and accommodating of a strict size constraint imposed by the customer at that time. This size constraint limited the design opportunities to achieve the desired functions, but is no longer a constraint for this iteration.

This iteration (started September 2013 and ended May 2014) involves a complete re-design, changing the old 'bench' design to a rotational system. This design was chosen for multiple reasons – in order to better meet customer needs, to comply with a significantly reduced project budget, and to increase the potential customer base. Additionally, this iteration improves upon the original design by making the device 40% lighter and far less complicated to assemble.

The system is being designed specifically for use in a Sonar class sailboat, which is recognized as the premier sailboat class for Paralympic racing. The end result is a functional system with extensive design, build, and installation documentation. In order to help the greatest number of people possible, the device itself will not be sold. Instead, the design documentation and easy-to-use assembly instructions will be publicly available in a free, downloadable format. There is market potential for this assistive device among disabled sailors or adaptive sailing programs that desire to have their own device.

PROCESS (OR METHODOLOGY)

As prescribed by the general senior design procedure, the entire first semester of the two-semester timeline was a planning and design phase. Much of this planning involved input from the customer (namely, Caitlyn Ridgely of Piers Park Sailing Center) in order to draft a list of customer requirements and draw from that a list of engineering requirements. Input during this customer phase was also given by Keith Burhans. Keith's extensive sailing knowledge, and, particularly, his extensive knowledge of the needs of the disabled sailing community, was instrumental during this phase.

Table 1 shows the final customer requirements that were reached after multiple iterations. The decision was made to separate the customer requirements into two separate categories – one for any potential person in the jib trimmer role who may be using this device, and another for the actual customer figurehead, Piers Park Sailing Center in Boston, MA (to whom the completed product from this senior design project is going). Calling out two separate

Customer Requirement Number	Importance	Customer	Description
CR 1	1	Jib trimmer	Move between port and starboard (for weight distribution)
CR 2	1		Trim jib lines
CR 3	2		Can be used for racing
CR 4	1		Safe for user
CR 5	1		Safe for crew
CR 6	1		Support the user
CR 7	2		Typical entry/exit is easy
CR 8	1	Piers Park	Easy to assemble
CR 9	2		Volunteers can install/uninstall without extensive training
CR 10	1		Does not designate a specific boat for use solely with device
CR 11	2		Easy to reproduce
CR 12	2		Low cost
CR 13	2		Can be used with wide range of users
CR 14	1		Works specifically in Sonar hull
CR 15	1		Does not damage boat
CR 16	1		Does not require boat modification
CR 17	1		Can be used in salt-water environment

Table 1 – Customer Requirements

Engineering Reqt #	Source	Function	Metric	Unit of Measure	Marginal	Target	Direction
ER 1	CR 1	Minimize time to move between port and starboard	Transfer time	Sec	5	2	↓
ER 2	CR 2	Access to jib lines	User reach distance	in	25	15	↓
ER 3	CR 3	Complies with ISAF/IFDS regulations	Does design only contain mechanical parts?	Yes/No	Yes	Yes	x
			distance between existing bench and seat	mm	200	minimize	↓
			Does design require boat modification?	Yes/No	No	No	x
			Is fixture permanently fastened to boat?	Yes/No	No	No	x
ER 4	CR 3, CR 11	Lightweight	Weight	lbs	100	50	↓
ER 5	CR 4	Device secure in boat	Displacement from secured position	in	TBD	TBD	↓
ER 6	CR 4, CR 5	Minimize pinch points	Number of potential pinch points	Count	TBD	0	↓
ER 7	CR 4	Able to see surroundings	Unobstructed field of view	%	75	100	↑
ER 8	CR 4	Safe in emergency	Boat release time	Sec	5	2	↓
ER 9	CR 4, CR 6	Secure limbs that the user can't control themselves	Are limbs secured?	Yes/No	Yes	Yes	x
ER 10	CR 7	Minimize entry time	Time to get into seat	Sec	5	2	↓
ER 11	CR 7	Minimize exit time	Time to get out of seat	Min	5	2	↓
ER 12	CR 6, CR 13	Maximize weight capacity	Weight capacity	lbs	220	265	↑
ER 13	CR 17	Corrosion resistance	Are all components chosen for corrosion resistant properties?	Yes/No	Yes	Yes	x
ER 14	CR 9	Easy to install	Time to install	Min	20	5	↓
			Number of installation steps	Count	TBD	5	↓
ER 15	CR 1, CR 2, CR 4	Maximize range of movement	Distance from boat centerline	in	21	24	↑
			Degree of rotation	Degree	+/- 30	+/-45	↑
ER 16	CR 4	Minimize possibility of boom to head collision	Vertical distance between seat and boom	In	33	38	↑
ER 17	CR 8, CR 11, CR 12	Machining minimizes the use of specialized equipment	Percentage of custom parts used in design (custom parts cannot be purchased 'off-the-shelf' in a store or online)	%	15	5	↓
ER 18	CR 8, CR 11, CR 12	Design has minimal manufacturing time of components (custom parts)	Percentage of custom parts used in design (custom parts cannot be purchased 'off-the-shelf' in a store or online)	%	15	5	↓
ER 19	CR 10	Easy to remove deivce from boat	Time to remove	Min	20	5	↓
			Steps to uninstall device	Count	TBD	5	↓
ER 20	CR 13	Can accommodate multiple body types	% of users who find seat "comfortable"	%	60	75	↑
ER 21	CR 14, CR 15, CR 16	Designed to Sonar dimensions and tolerances	Secure fit in Sonar	Yes/No	Yes	Yes	x

Table 2 – Engineering Requirements

'customers' was important in order to ensure that all requirements were being met properly. Piers Park Sailing Center, as an organization, has specific requirements that an individual user would not have; likewise, individual users have needs that are not applicable to an organization. The importance category on the table is rated on a scale of one through three - one being of the utmost importance, and three being the least critical. Seventeen total customer requirements were created, translating into 21 total engineering requirements. The engineering requirements are the technical specifications that need to be met in order to ensure that the customer requirements are met. For example, if the question "how" was asked about a given customer requirement, the corresponding engineering requirement would provide the answer to the "how" question. For each engineering requirement, a marginal and target goal was established. In order to make sure the engineering requirements are met, a detailed set of tests and test plans were developed. The test plan summary is provided in Table 3 below.

After creating the engineering requirements, potential risks were brainstormed and compiled in a Risk Analysis table. Analyzing and understanding potential risks and drafting mitigation strategies is a key step of any project. Since the jib transfer system is responsible for safely moving a human being, many of the risks centered around making sure the user would stay safe in all aspects of device operation. In order to assign a more empirical value system to these risks, a "hazard score" was used. A hazard score is produced by multiplying the risk's severity score by its probability score. The severity score ranges from one to three – one being not ideal, two having potential for damage, and three causing a complete system or project failure. The probability of occurrence was also rated on a one to three scale, with one being unlikely, two having a 50% chance, and three being probable. Multiplying across a risk's severity and probability scores gives the hazard score, which can then be used to compare each risk to determine its relative importance on a more empirical scale than completely relying on assumptions.

THE DESIGN

The system is made primarily of two-inch diameter, schedule 40, PVC piping. This material was chosen for a number of reasons. Through independent research and consultation with Piers Park Sailing Center in Boston, MA, the team determined that PVC is a popular and commonly used material for pre-existing adaptive sailing devices. It is well liked for its water resistance, its relatively lightweight nature, and its cost-effectiveness. Additionally, it is a familiar, easy-to-access, and easy to work with material. Its 'unprofessional' look creates a more inviting feel for users. Alternative materials, such as wood, carbon fiber, metal, and fiberglass, were considered, but were determined to not have the same ideal combination of properties.

Figure 1 – Jib Transfer System

The main PVC structure sits atop a wooden, circular platform, constructed of marine-grade plywood. This platform is mounted atop an aluminum lazy susan circular bearing. The underside of the bearing is mounted on a marine-grade plywood base. This base supports the bearing, stabilizes the entire system, and protects the boat deck from damage. The base is securely mounted to the boat deck via the Sonar's bilge access port. This approximately 16" x 7" access port in the foredeck of the Sonar allows for stabilizing mechanisms to be fed through the system's access port and positioned under the main deck. The stabilizing mechanism consists primarily of two, one-inch square aluminum tubes, cushioned by four rubber stand-offs. All of the marine-grade plywood components are finished with a substantial coating of epoxy paint for additional water fastness.

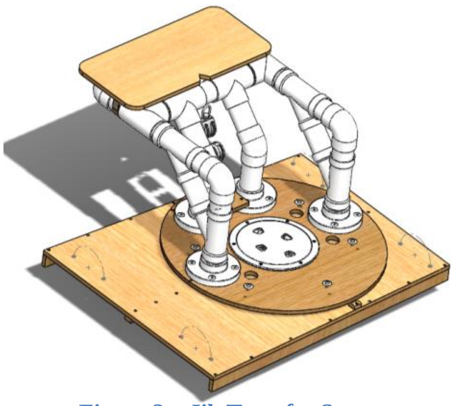

Figure 2 – Jib Transfer System (without seat)

The rotational system also has a braking and locking system. This system locks in place automatically at full port and full starboard positions. A pulley system attached to the braking mechanism allows the user to easily disengage the lock and/or brake in order to swing to the other side by pulling vertically on the line fed through the seat. The braking mechanism is attached to a spring, which surrounds a shoulder bolt. The spring is tensioned to cause the bolt head to drag across the lower base plate during the entirety of the swinging motion. This dragging creates friction, which is the source of the constant braking force. When the user gets to full port or full starboard, the bolt head will automatically drop into a hole that has been drilled from the base plate, locking the user into place. Under light wind conditions, or in any scenario where the boat does not have a great heel angle, the user can cleat the brake line so that the brake stays fully disengaged, and the chair will swing freely from side to side. Consequently, the line can be cleated at any position to allow for partial braking as necessary.

This design also accounts for securing the user's legs in a safe position. The ability to secure the limbs that the user cannot control was a concern for the prior jib transfer bench that this re-design addresses and solves. The user's feet will be resting directly atop the white circular deck plate, which puts the user's legs just inside and vertically aligned with the vertical PVC legs. If the user's legs need additional securing, this puts them in the optimal position for strapping their legs in place adjacent to the PVC legs.

At the top end of the PVC structure sits a marine-grade plywood platform. The choice to incorporate this platform into the design, rather than bolting a chair directly to the PVC, was a strategic decision. Having this platform provides an easy and accessible location for any chair to be affixed. This allows for the same design to incorporate a wide range of users because the specific chair for the design can easily be custom-tailored to meet anyone's or any group's specific needs. The suggested seat for general-purpose use is a cushioned, weather-resistant reclining seat with foldable armrests.

It should also be noted that the system was specifically designed for use in a saltwater environment. Although the design should not be completely submerged in saltwater at any point in its life, it is expected to be splashed with saltwater relatively frequently. As a result, all of the construction materials, including the specific types of metals used for the hardware, were purposefully chosen to comply with this scenario and produce a system ready and able to withstand these conditions.

Although a jib transfer bench was designed by a different group of RIT students (Senior Design Group P13031) the year prior, this is a complete re-design in almost every way. Last year's bench was a linear movement device, while the current iteration is based on a rotational platform. The rotational platform design actually increases ease of production, ease of installation, and takes up less space in the boat to allow for less interference with other crewmembers. Additionally, a major improvement is the total device weight, which is particularly crucial during boat installation. The previous transfer bench was made primarily of 6061 Aluminum. This material is not only heavy, but also costly. The current jib transfer system has reduced system weight by 59%, due primarily to the exclusion of Aluminum and inclusion of PVC.

RESULTS AND DISCUSSION

The design enables the jib trimmer to rotationally swing around from one side of the boat to the other (hovering over the Sonar's native bench). It positions the disabled jib trimmer in almost the exact same position in which he would normally sit, except approximately six inches higher. This seating arrangement keeps the user in a very similar position relative to the jib lines in order to ensure that access to these is not reduced. It also ensures that line of sight is not reduced, as the jib trimmer is also the 'eyes' of the boat, alerting the skipper and crew to hazards or boat traffic. In fact, if anything, line of sight is increased, since the user is higher than the bench itself.

During system operation, the chair will start in full starboard or port position, locked in place directly over the Sonar's native bench. When the user wants to move to the other side, he will pull vertically on the brake line to disengage the lock, which will simultaneously engage the brake. Ideally, he will be on the 'high' side of the boat at this point, so gravity will assist in allowing him to swing down to the 'low' side of the boat. When the system reaches the other side (180^0 from the starting position) the system will automatically lock in place.

Figure 3 – Jib Transfer System

If the boat is not heeled, or not heeled very much, gravity will not be of much assistance, and the brake will likely be too strong to allow for movement. If that condition occurs, the brake line can be cleated in the cleat located on the seat, adjacent to the line, which will hold the brake in the disengaged position. With the brake disengaged, the device will rotate freely and without resistance. At any moment, the brake can quickly and easily be re-engaged and locked into place at full port or full starboard.

Table 3 on the following page shows the test plan summary. Each specification maps to an engineering and/or customer requirement that needed to be met. Some of these tests require the device to actually be installed and sailed with in the boat, some just needed to be performed while installed in the boat but the boat could be stationary, and others yet did not require in-boat installation. The table shows that most conditions were met or exceeded. A green box and circle denotes that the spec was met, while a yellow box and triangle denotes a "caution" condition, where it is undetermined whether or not the specification was met. A red box with an X would denote a specification not being met, but that condition is not reflected with any of these specifications.

P14031 Test Plan Summary

Spec #	Metric/Specification	Units	Marginal	Target	Direction	Test Plan	Sonar Needed	Sailing Req'd	Actual	Concluded Condition
S1	Transfer time	sec	5	2	↓	TP1	X	X	3 sec	O
S2	User reach distance to jib lines	in	25	15	↓	TP2	X		19"	O
S3	Does design only contain mechanical parts?	yes/no	Yes	Yes	X	TP3			Yes	O
S4	Distance between existing bench and seat	mm	200	minimize	↓	TP4	X		6" (152.4 mm)	O
S5	Does design require boat modification?	yes/no	No	No	X	TP3			No	O
S6	Is fixture permanently fastened to boat?	yes/no	No	No	X	TP3			No	O
S7	Device Weight	lbs	100	50	↓	TP5			51 lbs	O
S8	Device displacement from secured position	in	2	0	↓	TP6	X		0.75"	O
S9	Number of potential pinch points	count	5	0	↓	TP7	X		0, but there is 1 trip hazard	O
S10	User's unobstructed field of view (compared to no device use)	%	75	100	↑	TP8	X	X	100%	O
S12	Does the user have the option to secure their limbs?	yes/no	Yes	Yes	X	TP3			Yes	O
S13	Time to get into seat	min	5	2	↓	TP9	X	X	dependent on disability	Δ
S14	Time to get out of seat	min	5	2	↓	TP9	X	X	dependent on disability	Δ
S15	Weight capacity	lbs	220	265	↑	TP10			215 lbs (ANSYS simulation shows failure at ~300 lbs, but team could not test to device failure)	Δ
S16	Are all components chosen for corrosion resistant properties?	yes/no	Yes	Yes	X	TP3			Yes	O
S17	Time to install device in Sonar	min	20	5	↓	TP11	X	X	4.5 minutes	O
S18	Number of installation steps	count	10	5	↓	TP11	X		6 steps	O
S19	Max horizontal distance from boat centerline	in	21	24	↑	TP12	X		23"	O
S20	Degrees of rotation	degrees	+/- 30	+/-45	↑	TP13	X		+/- 90	O
S21	Vertical distance between seat and boom	in	33	38	↑	TP14	X		34.5"	O
S22	Number of parts requiring specialized equipment to manufacture.	count	5	0	↓	TP15			1 part	O
S23	Number of custom parts used in design (custom parts cannot be purchased 'off-the-shelf' in a store or online)	count	5	0	↓	TP15			1 part	O
S24	Time to remove device from Sonar	min	20	5	↓	TP16	X	X	2.5 minutes	O
S25	Number of steps to uninstall device	count	10	5	↓	TP16	X		6 steps	O
S26	% of users who find seat "comfortable"	%	60	75	↑	TP17			Mfgr chooses seat that fits needs	Δ
S27	Depth of plywood groove after 13500 rotations (~5 years)	in	0.23	0.10	↓	TP18			depth = 0.025 in	O

Table 3 – Test Plan Summary

BUDGET & MARKET ANALYSIS

The design team was granted a budget of $1000 through the RIT Multidisciplinary Design Fund to use for building and testing (a 60% reduction from the prior year's budget). However, due to the fact that the design, build plans, and assembly instructions will be freely available to the public, the goal is keep the system cost as low as possible. By keeping the cost as low as possible, this increases the number of potential users, and increases the possibility of introducing more people to the joys and thrills of sailing. The total cost of the entire system is approximately $630. Due to the previous year's project going over budget, this is a 79% reduction of total system cost.

Minimizing the number of manufactured parts and processes was a main focus during the design phase. This is one of the crucial aspects to making the jib transfer system accessible to others. Only common construction techniques are needed (cutting and drilling), and even those are minimal for this design. Once the system is constructed, assembly into the Sonar boat requires only one tool – an included hex wrench to hold four bolts in place while they are hand-tightened using thumb nuts.

The jib transfer system can be directly marketed to the user and to adaptive sailing centers. In the US alone, there are 59 organizations across 23 states that are recognized by US Sailing as offering certified adaptive sailing programs. Additionally, US Sailing also acknowledges more than 75 additional organizations offering adaptive sailing programs that have not yet undergone the certification process [1].

There is a 5.5% ambulatory (relating to or adapted for walking) disability prevalence among non-institutionalized working-age people (ages 21 to 64) in the United States, according to data from the 2011 American Community Survey [2]. This is an estimated 9.9 million people who have the potential to become sailors and who would have a need for this jib transfer system.

These statistics show that there is broad market potential for this system. The market for a product such as this jib transfer system is almost entirely untapped. Some individual adaptive programs have created their own devices, but a source of detailed plans and instructions on an analytically tested device seems to not exist. This jib transfer system would be the first readily accessible sailboat mobility device of its kind.

CONCLUSIONS AND RECOMMENDATIONS

The jib transfer system successfully allows a disabled user to act as crew in the role of the jib trimmer. This design reduces weight from last year's device by 59%, or 74lbs. The total system cost is reduced by 79%, and the in-boat installation time reduced by approximately 50%.

Last year's RIT senior design group (P13031) had a number of suggestions for areas of improvement, should future groups re-visit this project. These suggestions included reducing weight and cost, using more off-the-shelf parts and fewer machined parts, having better corrosion resistance, and potentially adding a brake mechanism. This new jib transfer system design addresses and improves upon each and every one of the items mentioned. In this entire design, there is only one part that must be machined; all other parts can be bought or made relatively easily with common tools and equipment to an average household garage owner. This is a major advantage in achieving the goal of enabling any person or organization to build a jib transfer system of his own.

Figure 4 – Jib Transfer System (top view for size reference)

In order to further aid in the accessibility of this device, all detailed drawings, the bill of materials, detailed and easy-to-understand build instructions, and easy-to-follow in-boat installation instructions have been produced and will be available online in a free and open format.

Going forward, recommendations for further improvements would include analysis on re-designing the locking mechanism to eliminate the only component that needs to be custom machined. In addition, analysis on the exact spectrum of disabilities that can potentially use this device would allow specific ergonomic changes to be made to address each in the most efficient way possible.

REFERENCES

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[2] Erickson, W., Lee, C., & von Schrader, S. (2012). 2011 Disability Status Report: United States. Ithaca, NY: Cornell University Employment and Disability Institute(EDI)

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