CHAPTER 11
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TRACK AND TROLLEY FOR COCKPIT CREW SEATS

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INTRODUCTION

A track and trolley system was designed for the B'Quest, a racing sailboat. The mechanical track (rail) system will be used to shuttle crewmembers who are quadriplegic and paraplegic around a circuit to each watch station in the cockpit. These watch stations include port and starboard jib sheeting winch, port and starboard mainsheet trimmer, navigator, and helm positions. The existing seats (shown in Figs. 11.2 and 11.3) will be mounted onto the rolling and rotating trolleys. A full-scale mock-up of the cockpit and aft decking has been constructed in order to test, evaluate, and modify the device before installation on the B'Quest. The mock-up is capable of being tilted at up to +35 to simulate maximum expected "heel," or roll angle, while sailing "close hauled" (as far into the wind as possible).

SUMMARY OF IMPACT

The complete assemblage of track, trolley, and motorized drive mechanism (the latter described in the following article) will allow individuals who are paraplegic and quadriplegic to move from watch station to watch station without leaving their seats. This innovation will greatly increase both safety and comfort for all members of the crew.

During rough weather, the possibility exists that a crewman will be injured or even hurled overboard while changing positions. The new system will reduce this possibility, since the only time a crew member will be out of his or her seat will be when he or she is moving from the cabin, up the companionway, and into a seat immediately adjacent to the companionway, or returning to the cabin.

TECHNICAL DESCRIPTION

Goals and Constraints

Design decisions were based on the following goals and constraints:

1. The highest part of trolley must be no more than 3″ above the deck on which it is mounted.

2. The traveler (mechanism on which seat rides) must negotiate helm arch, which adds 12″ of elevation to the seat. The 62″ width of the arch will include concave and convex radii, which the travel plate and bogeys must negotiate without interference.

3. The seat must rotate so that crewmembers can position themselves optimally with respect to duty stations. In particular, the seat must be properly positioned in relation to the foresail winch.

4. The seat must be held securely to the boat under at 35° of heel against dynamic loads of at least 500 lbs. The safety factor must be at least 3.0.

5. The apparatus must be corrosion-resistant and appropriate for a marine environment.

6. The apparatus must not have sharp projections or protrusions, which could either injure a sailor falling against them on a pitching deck or snare lines.

Tubular Track and Archway

The tracks (Fig. 11.1) are made of 1″ tubing, since tubing can be easily bent and, with proper material selection, can exhibit high strength and stiffness while being relatively light. The arched track at the rear of the cockpit behind the helm (Figs. 11.1 and 11.3) has a 62″ span with no support from the deck underneath it. Moreover, the helmsman and seat trolley weigh up to 250 lbs and can exert up to twice this force on the arch, as well as large twisting moments, due to pitching and heeling of the boat in rough seas. Therefore, the arch was designed with high safety factors. Each of the two tube rails is connected to two support tubes by welded gussets to form a truss with a right triangle cross-section (Fig. 11.3). The 9″ spacing between the trusses accommodates the motorized drive mechanism and third tube rail along which the drive translates.

The 3″ height restriction required that the rails be mounted as close to the deck as possible and still allow clearance for under-gripping vertical rollers. It was decided to weld stainless steel rails directly to 3/16″ thick stainless steel mounting strips.

Breakaway (Drop-Down) Track Section

The breakaway section adjacent to the companionway at the front of the cockpit (see Figs. 11.1 and 11.2) gives crewmembers a clear pathway to get below deck without tripping over the rails. The ends of the tubes are slotted, and they mate with slots in the fixed rails. The breakaway section is secured by telescoping pins that engage the fixed rails. When dropped down, this track section is only 1¼″ high.

Trolleys and Bogeys

The bogeys have both horizontal and vertical rollers to retain the trolleys on the track, even when the boat is pitching and rolling (Figs. 11.4 and 11.5). In order to meet the tight height requirement, the bogeys were recessed into the trolley plate as far as possible. The bogeys are retained in the travel plate by capture rings which mount on the bottom surface of the plate. In order to negotiate turns, the circular sockets in the base plate for the outboard bogeys were extended into ovals, allowing the bogeys to remain centered on the rails (Fig. 11.4). In order to more securely retain the trolleys on the track, stainless steel washers will be welded to the heads of the vertical shaft bolts for the side wheels (Fig. 11.5).

The base plate includes a front "wing" with a series of ½″ holes spaced 15° apart (Fig. 11.4). This allows the rotating plate, which directly supports the chair frame, to rotate over a + or - 45° range. In order to lock the rotating plate into each position, a toggle device was designed to fit under the front lip of the travel plate (Fig. 11.6). It is essential that any device at this location not have protrusions of any kind, which would injure crewmembers' legs, or snag clothing or lines. A spring-loaded throw-bolt rides on a ramp which, when pushed in one direction disengages the bolt from the rotating plate, and, when pushed in the other direction, allows the bolt to re-engage. A knotted cord operates the bolt, which is led through the holes in the chassis to the front of the travel plate. In this way, there are no parts extending into "sailor-space".

The rotating plate is mounted to the travel plate by a 1.25″ bolt within a Delrin-AF bushing (Fig. 11.4). The rotating plate is separated from the travel plate by a 1/16″ thick Delrin-AF gasket that reduces friction for easy seat rotation. The bogeys are similarly isolated and supported by Delrin bushings and disks.

We determined that the concave radius in a 12″ helm arch would create interference (Fig. 11.3), so the height of the arch was reduced to 9″, with consent of the client. The final design barely exceeds the 3″ height requirement, as the total height to the rotating plate top surface is 3.125″.

Rail pairs are located 10″ apart center to center. Turning radii are 5″ and 15″ at the stern and 10″, and 20″ forward. Fitting prospective templates to the deck surfaces of the sailboat and finding the best fit for attaining the proper duty stations determined these dimensions. Model travelers were constructed to define the best compromise between bogey spacing on the traveler, and workable turning radius. During design iterations, the bogey spacing on the traveler had to be decreased in the side-to-side dimension from 10″ to 7.5″ in order to accommodate the turning radii.

Brake

A mechanical brake under the trolley base plate (Fig. 11.9) is used to slow or stop the seat trolley when the boat is pitching or rolling. The brake is similar to a bicycle brake, although it is significantly stronger, since it must exert at least 600 lbs of clamping force to generate enough friction to stop a trolley rolling down a 35° incline at maximum heel. Stainless steel springs press the rubber brake pads against the tube rail. The brake is normally engaged, and is released by a hand lever via a sheathed cable (Fig. 11.10) with a mechanical advantage of 30:1, meaning the crewmember must exert only 20 lbs force on the handle. The brake can be held open by a retaining pin which can be quickly released by tugging on a lanyard, to quickly arrest a runaway trolley. All parts will be made of 304 rolled stainless cold, except for the brake pads.

Materials

The harsh conditions of exposure to the elements and seawater dictated that all components be corrosion proof. Hastelloy C-276, stainless steel alloys 304 and 316L, and Super Duplex (Zeron 100) stainless steel were considered. Since the B'Quest is raced, all components must be as light as possible. Super Duplex is three times stronger than 316L and more resistant to seawater corrosion, and is less dense than the Hastelloy C-276. Super Duplex is the material best suited for this application due to its strength, corrosive resistance, and cost (approximately $5.00/foot). Therefore Super Duplex (Zeron 100) will be used for the tube rails of the actual on-board article, while the prototype rails will be made of alloy 316L to demonstrate proof of concept.

The bogey housing and press fit horizontal axle for the upper roller were machined from 316L stainless steel. The two vertical bolts (axles) for the side rollers and the bolts connecting the bogey assemblies to the base plate are stainless steel 304 bolts modified to design specifications. Although stainless steel 304 is not as corrosion resistant as 316L, the yield strength of 304 is 160,000 psi, three times that of 316L, which is sufficient to withstand the dynamics forces with a safety factor greater than 3.

Anodized aluminum alloy 6061-T6 was used for the seat mounting plates and toggle assembly (the toggle assembly releases, and locks together, the plates to allow rotation of the seat). Aluminum 6061 combines relatively high strength, good workability, and high resistance to corrosion, and readily accepts coatings.

Delrin AF was used for the large, low friction washer sandwiched between the aluminum rotating plate and base plate, as well as for the washers and bushings for the bogeys, rollers, and "king pin" about which the rotating plate spins. Delrin AF is an acetal resin with PTFE fluorocarbon fibers distributed throughout, giving it the characteristics of Teflon. It exhibits low moisture absorption, high stiffness, low coefficient of friction, and it is easy to machine adapt.

On-Board Article Versus Prototype

The on-board system will incorporate modifications stemming from testing the prototype. One change has already been planned. The prototype for dry land testing has tubular tracks made of thick-walled stainless steel alloy 304, because it was readily available and donated by Valley Metals in San Diego. However, weight is an important consideration for a racing sailboat, so the actual article that will be installed on the B'Quest will employ thin-walled, lighter and stronger, "super duplex" stainless steel tubing for the tracks.

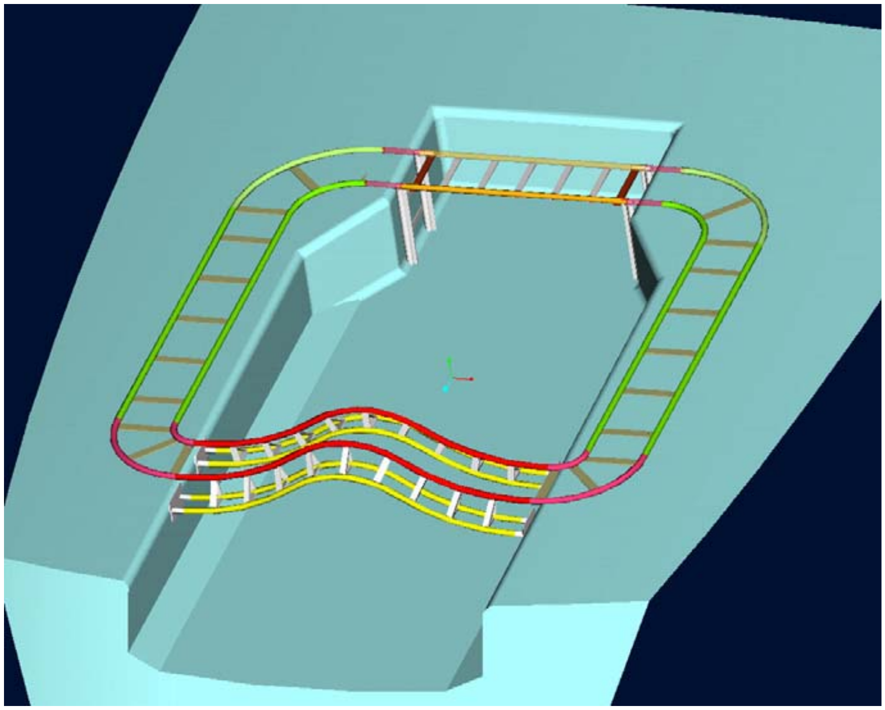

Figure 11.1. Twin Tubular Track Mounted on Cockpit.

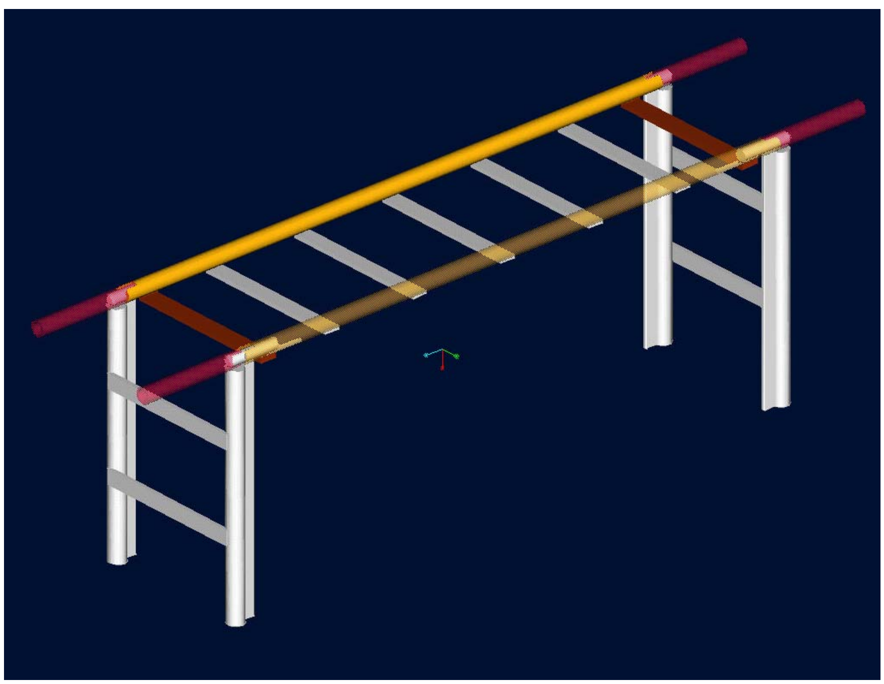

Figure 11.2. Drop-down Portion (yellow) of Motorized Drive.

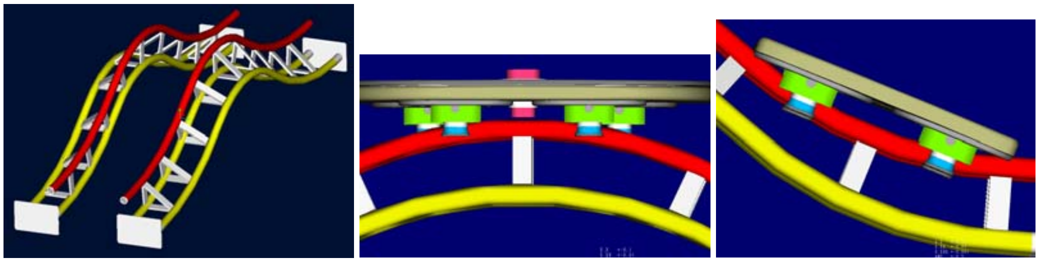

Figure 11.3. Arched Truss behind Helm (left), Check for Interference between Tube Rails and Bogeys of Trolley over Convex (middle) and Concave (right) Truss Sections.

Figure 11.4. Trolley Underside with four Bogeys that Retain Trolley on Tracks (CAD Model, left; Prototype Hardware, right).

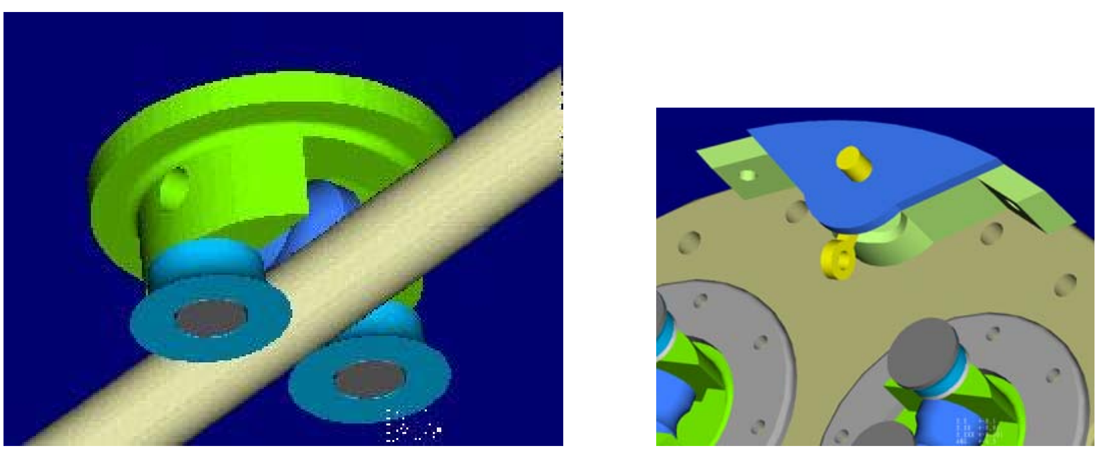

Figure 11.5. (Left) Trolley Close-up. (Right) Rotating Bogey Close-up (green).

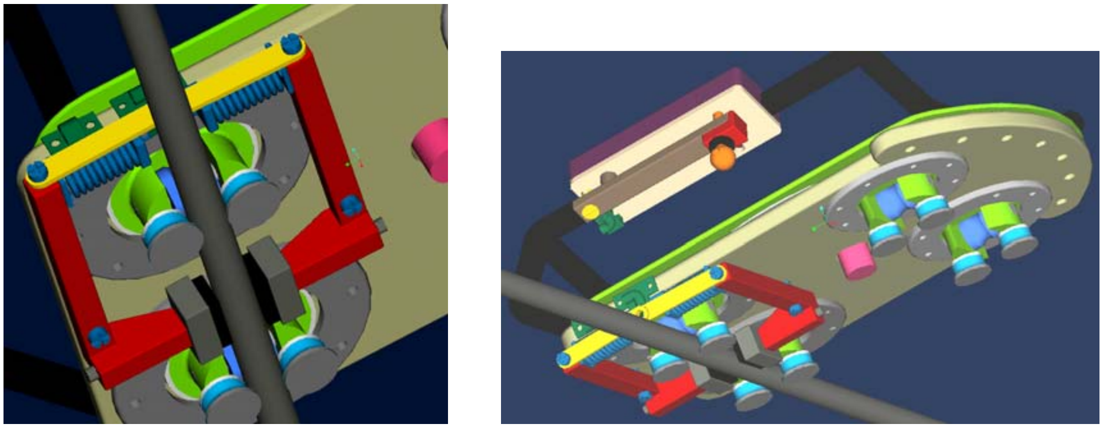

Figure 11.6. (Right) Bogey Riding on a Track Rail. (Left) Lock Pin for Rotating Plate.

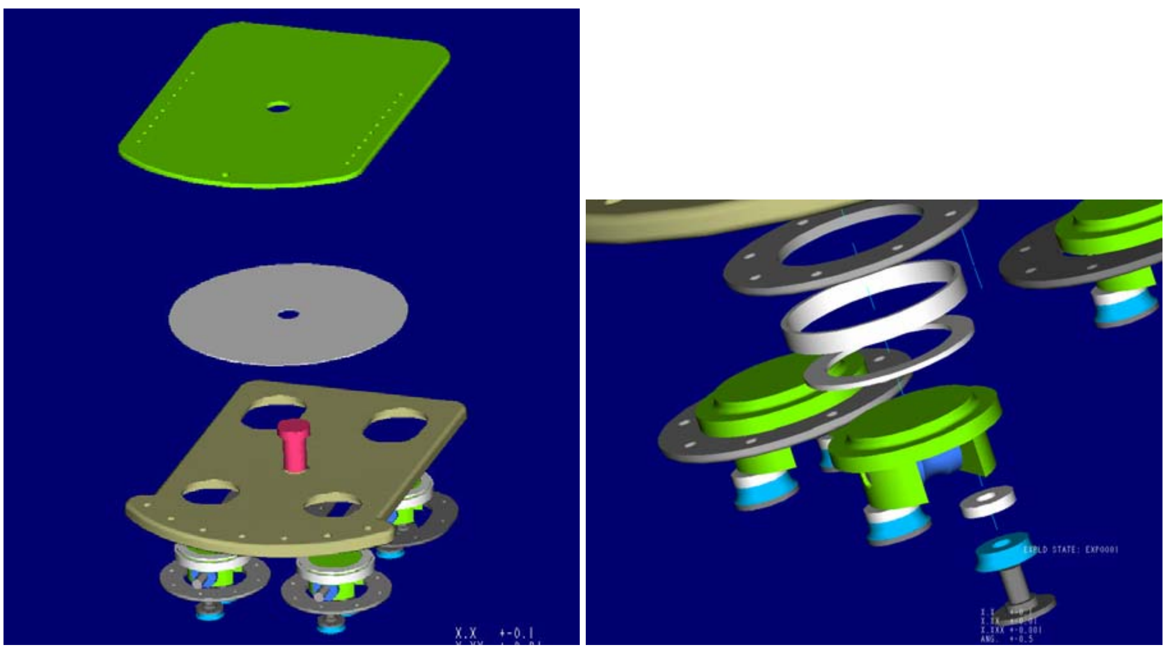

Figure 11.7. (Right) Trolley Underside with Brake. (Left) Trolley Underside with Brake and Brake Handle (cream & tan box).

CREW OVERBOARD RETRIEVAL SYSTEM

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INTRODUCTION

Currently, there is no known dual-purpose system that will take a person who uses a wheelchair from the dock to a boat, or a way to rescue a person who has fallen overboard. For small boats there is no efficient means of rescuing a person out of the ocean, a process that proves more difficult if that person does not have the full use of his legs and arms. The purpose of our design project is to simultaneously develop a reliable and efficient mechanical system that will do both the above tasks, and not compromise the sailing efficiency of the boat.

The design has three major divisions. The first is the arch davit that serve as the support system. The second sub-division is the turret that is capable of rotating 360 degrees, and sits on the turret mounting plate. The third major component is a square tubular beam seven feet in length. The beam supports the shuttle that is able to transverse the length of the beam.

The device is designed to mount on the aft section of a boat, and be controlled by mechanical winches that are mounted onto the arch davit. The entire device is purely mechanical, and designed to be operated by persons of limited upper body strength.

SUMMARY OF IMPACT

This system provides a method for people with limited upper body strength to safely board a boat and to rescue an overboard person. See Figures 11.8 and 11.9.

TECHNICAL DESCRIPTION

The arch davit is stainless steel tubing shaped in a form of an arch with lateral support trusses. The top of the arch davit has a mounting plate to support the turret system. The turret system consists of two thrust bearings, an upper and lower plate, and a v-belt drive system. A square tube assembly with a shuttle attaches to the turret. The arch davit had to be designed with the following constraints: 1) it had to be built on the aft section of the boat using existing mounting holes, keeping in mind that additional holes will have to be made; 2) the davit had to clear existing structures such as the main boom, the helm chair, and the stanchions; and 3)it had to be designed with 303 stainless steel, 1 ½" outer diameter tubing with ¼"thickness to support the loads.

The turret system involves two thrust bearings with the arch davit mounting plate between the two bearings. With this configuration, the upper and lower bearing share the load equally and provide for more surface area for the bearings. The upper plate rests on the upper thrust bearing so that it is free to rotate. The plate has a 2" hole bored through the center to allow for the path of the pulley lines. There is a dovetail c-channel mounted on the rear of the upper plate to allow for the securing of the square-beam cable. There are also two rabbit-ear flanges mounted on the front of the upper plate to provide the pivot for the square beam assembly. See Fig. 11.9.

The square-beam assembly is reinforced with a gusset that is welded on it to provide lateral support. Each side of the square tubing is 2 ½' with 1/8" thick walls. Attached to the beam is an eye-bolt that is 2' from the end and is used for the support cable. The square tubing provides a surface for the shuttle to ride on as well as provides for a path for the pulley lines to run through. The square beam was designed to hold a 1,000 pound static load and a 400 pound repeated load.

The shuttle is a U-shaped assembly that rides along the top and bottom surfaces of the square tubing. The sides of the shuttle are reinforced with flanges to keep the U-shape from spreading. A pulley is mounted under the shuttle to provide for the movement of the retrieval hook.

The two winches used on this project are off the shelf items. A 1:1gear ratio winch is used for moving the shuttle laterally. And a 50:1 gear ratio winch is used to lift up to 1,000 pounds from the water. A flexible drive shaft, another off the shelf item, is used to rotate the turret mechanism.

Figure 11.8. Functional Mockup of Extended Gantry Crane.

Figure 11.9. Turret and Furling Mechanism Close-up.

CENTER PEDESTAL GRINDER FOR RACING SAILBOAT

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INTRODUCTION

Winches are ubiquitous on sailboats, used for hauling in and tensioning a variety of sail handling and control lines. Traditional winches use a crank handle mounted directly to the vertical axis of the drum. This configuration requires substantial trunk and lower body strength to power the lateral motions required of the handle. This motion can pose ergonomic challenges for able-bodied sailors, and can be nearly impossible for sailors with physical disabilities or lower body strength limitations.

An improved device provides a pair of cranks rotating around a horizontal axis, using an opposing motion, like bicycle pedals. This configuration, often known as a pedestal or "coffee grinder," is commonly found on larger sailboats. Larger sails lead to higher control line tensions, and larger crews allow crew members to be dedicated primarily to winch grinding. Gearboxes provide multiple speeds, and allow the power to be directed to different winch drums.

The goal of this project was to design a winch pedestal that could be rotated for use by a crewmember sitting on either the port or starboard side of the cockpit of a 40′ racing boat. A design variation looked at the feasibility of a lower, foot operated version for those with upper-extremity limitations or amputation.

SUMMARY OF IMPACT

The center pedestal grinder provides a method for crew members with limited lower or upper body strength and mobility to perform the task of raising and adjusting the sails of a boat.

TECHNICAL DESCRIPTION

The center pedestal winch grinder employs a "coffee grinding" mechanism that is mounted in the center of the boat's cockpit, and connected to winches on either side of the boat. The pedestal grinder is typically operated with both hands while in a standing or crouching position. The students' design enables crewmembers in a seated position to effectively grind with a powerful, bicycle-like hand motion at chest level.

The key components of the prototype center pedestal consist of a commercial gearbox and a locking rotation mechanism. The handles attach to the side shafts of the gearbox, inside which three bevel gears convert the handle rotation around a horizontal axis into rotation of a vertical center shaft inside the pedestal. The bottom of the gearbox is attached to concentric cylindrical components that allow for rotational positioning of the handles for different crew positions. This rotation mechanism employs a locking pin to rigidly fix the position of the gearbox at various locations. The rotation base mounts atop the shaft pedestal and uses two aluminum plates to bolt to the deck. Within the pedestal, the drive shaft interfaces with a standard below-deck drive system.

Figure 11.10. Center Pedestal Grinder Prototype.

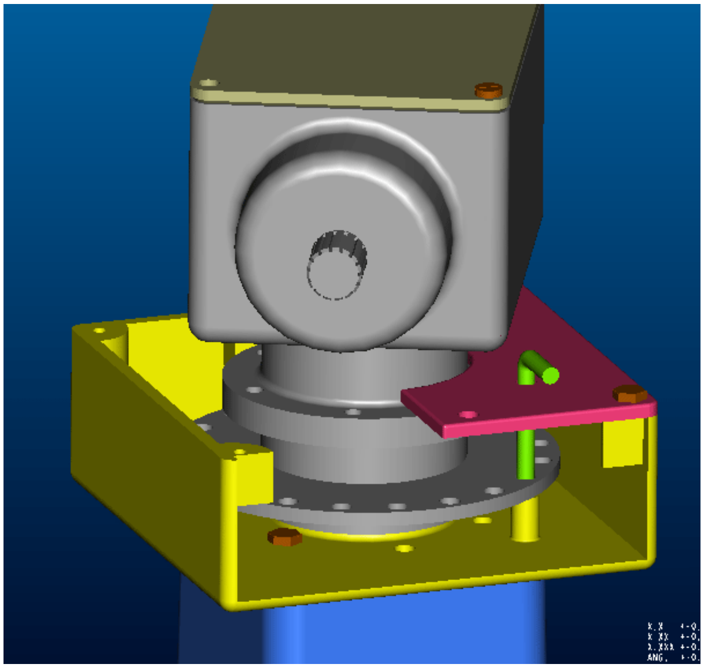

Figure 11.11. Gearbox and Rotating Mechanism Assembly Drawing.

WINCHTOP GRINDER FOR RACING SAILBOAT

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INTRODUCTION

A winch is a mechanism that contains a drum on which rope is coiled, and can be tightened with a crank or handle that allows easier adjusting or hoisting of sails. Traditional winches, ubiquitous on boats, rotate (grind) in a horizontal plane and are not easily operated by able-bodied sailors, much less sailors who may use wheelchairs, have amputations, or otherwise have limited upper or lower body strength. An improved device rotates in a vertical plane using an opposing motion like a bicycle crank, and allows users lacking lower body strength and flexibility to operate them. The goal of this project was to design a mechanical adapter to an existing (traditional) winch, converting the winch from a handle-cranking device (operated on a plane) to a vertical, bicycle hand-rotating motion. This winch-top grinder must be designed for strength, ease of attachment/detachment, and corrosion resistance. The grinder must also operate both forward and reverse, in order to utilize the two-speed gearing of the winch.

The Challenged America sailing program is modifying a Tripp 40 racing sailboat to accommodate a primarily disabled crew. This program is located in San Diego Bay and currently has over 100 members. The winch-top grinder will be used by several of the regular crew members during pleasure, and competitive, sailing.

SUMMARY OF IMPACT

The winch-top grinder provides a portable device for crew members with limited lower body strength to perform the task of raising and adjusting the sails of a boat.

TECHNICAL DESCRIPTION

The winch is a rotating drum on top of which is a star-shaped socket into which normally fits an L-shaped handle. This handle rotates in the horizontal plane and can easily be moved to different winches to control the various rope lines. The winch-top grinder replaces the handle and converts an opposing vertical motion into a horizontal rotation that turns the winch.

The winch-top grinder consists of handles attached to a commercially available gearbox, which is connected to a winch via a drive shaft. The gearbox is cast aluminum (Motion Industries) containing bevel gears with two input and one output shafts. Couplings and connectors are designed to attach to the handles and drive shaft, which terminate in the star spline socket in the winch top. The winch-top grinder is designed to withstand 80 ft-lb of torque. Testing of the grinder demonstrated that it could be moved from an old to a new winch in less than 5 seconds. This design can be used in a variety of sailboats and for individuals with limited mobility, such as seniors, as well as crew members with disabilities.

Gear box	$260
Aluminum plating	$15
Coupling	$10
Shaft Collar	$35
Keys	$3
Total	$323

The final estimated cost is approximately $1000

Figure 11.12. Winch-top grinder in use on a racing sailboat.

Figure 11.13. Winch-Top Grinder: Fabricated Prototype (left) and CAD Assembly Drawing (right).

MOTORIZED DRIVE FOR COCKPIT SEAT TROLLEY

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INTRODUCTION

The purpose of this project was to create a motorized drive mechanism to be integrated into a track and trolley circuit for moving crew seats around the cockpit of a Tripp 40 sailboat, the B'Quest. The motorized drive mechanism functions only on the rear portion of the track circuit (behind the wheel). Its function is to propel crew seats, that are mounted on trolleys, over an arch in the track that exists to enable the helmsman to see over the cabin. Only one of four seat trolleys is latched to the drive mechanism at any given time, since only one seat is on the rear portion of the track (i.e., the helmsman's position) at any given time.

The motorized drive mechanism latches onto the bottom of the seat trolleys and runs along a third tube rail between the two tube rails that support the seat trolleys. The drive system consists of four polymeric drive wheels mounted in a stainless steel chassis. Attached to the chassis is a 24V DC motor of sufficient of power and torque to transport a sailor seated on a trolley over the rear arch (across the cockpit) in 10 seconds. A chain drive is uses power from the motor to the drive wheels. This system is controlled via an umbilical switchbox attached to the sailor's seat latched to the drive mechanism The power for the motor is supplied by the existing 12V DC electrical system on the boat.

SUMMARY OF IMPACT

There currently is a motorized helm chair on the B'Quest that translates left and right (port and starboard) behind the wheel, but a sailor with physical disabilities must be carried to, or assisted into, the seat. Moreover, the current device has several flaws: it is heavy (a distinct impediment for a racing sailboat), draws too much electricity from the boat's batteries, and is unreliable.

The new motorized drive system will correct these deficiencies, will interface with the track-and-trolley system (see the previous article), and propel a seated crewmember along the arch in the track behind the helm that allows the helmsman to see over the cabin.

TECHNICAL DESCRIPTION

The motorized drive mechanism is designed to propel a sailor (who is disabled or able-bodied) sitting in a chair trolley over a 9" high arch in the tubular track behind the helm of the B'Quest. This device had the following requirements: 1)must translate the crewman and seat (250 lbs total) from one side of the cockpit to the other in 10 seconds;2) must use the existing 12-volt power supply on the boat (lead-acid marine batteries); 3) cannot have any pinch points or other hazards; and 4) must be rugged, weatherproof, and reliable.

The motorized drive mechanism is illustrated in Figs. 11.14 and 11.15 below. Its components are also described below.

Chassis

The chassis houses the other components and must withstand the 600 lb clamping force needed generate enough friction (300 lb) to propel a sailor and seat trolley. The chassis consists of a length of 2"x 4"x 0.25" wall 316L Stainless Steel rectangular tube. Holes were machined for the bearings, and holes were drilled and tapped for the screws for the retaining plates. An angle bracket is used to mount the motor.

Rollers

The rollers are the interface between the axles and the center drive rail and are cast, or machined from, polyurethane rubber. The inner diameter of the rollers is undersized to minimize slippage with the axles. The outer diameters are oversized to provide the necessary clamping force on the drive rail.

Axles
The four axles transfer the clamping force from the polyurethane roller to the chassis and transmit power from the sprockets to the rollers. The axles are made of type 15-5 PH stainless steel, selected for its combination of corrosion resistance and superior yield strength of 145 kpsi, which far exceeds the 25.4 kpsi stress required to achieve the proper clamping force. The axles were turned to the appropriate diameters on a lathe. The larger diameter accommodates the rollers, and the smaller diameter slips into the bushings, bearings, and sprockets. The large diameter section has channels machined in it to grip the polyurethane wheels to prevent them from slipping. There are two flats on the axle for the set screws in the sprockets.

Bearings
The bearings are used to support the axles. The bearings used are ABEC 1, R6, 440C Stainless Steel, double sealed bearings. The bearings are held in place by the bushings and retaining plates. The bearings are rated for a 750 lbf load.

Bushings
The purpose of the eight bushings is to keep the drive wheels centered in the chassis. The bushings are made of Delrin®. The material was rejected due to the required diameter on a lathe and drilled to accept the axle. These keep the rollers in proper alignment and reduce friction losses without lubrication.

Retaining Plates
The two retaining plates are used to capture the bearings in the chassis. The original design did not call for the use of retaining plates; instead the bearings were to be pressed into the chassis. The change was made to make the device more serviceable. The revised design requires only a regular screwdriver to completely disassemble the chassis, axles, and bearings. The plates are made of 16 gauge 316L Stainless Steel. The plates were cut to size and the appropriate holes were drilled for the axles and screws.

Sprockets
The sprockets are used to transfer motive power from the chain to the axles. The sprockets are for an ANSI 35 chain and are made of 304 Stainless Steel. The sprockets were drilled and tapped for two set screws spaced 90° apart. Size 8-32, Stainless Steel, cup point set screws are used.

Chain
A roller chain is used to transfer power from the motor to the sprockets on the axles. The chain is an ANSI 35, 300 series Stainless Steel, roller chain rated for 1440 lbs of tension. The chain can be routed in such manner that all four wheels are driven with the addition of two more sprockets not shown in Figs. 11.14 and 11.15.

Motor/Gearhead
A DC motor is used to provide the motive effort. The power required has been calculated and a motor was sourced. Initially, traditional 12 VDC motors were examined for this application, but the size of these motors was a problem, since motors that met the power requirements were typically 11″ long x 6″ diameter. The motor selected was a model TG2300 DC brushless motor from Thin Gap Motors, capable of providing 70 in-oz of torque at 2000 rpm using a 24V supply.

The increase from 12 to 24 volts allows for a more compact motor. A step-up voltage converter, normally used for solar power applications, was chosen. At its peak torque this motor draws 7.5A. The motor is internally sealed, and its dimensions suit the application, 3½″ long x 3″ diameter. A gearbox with a 20:1 reduction will be obtained from CGI to achieve the required torque and speed.

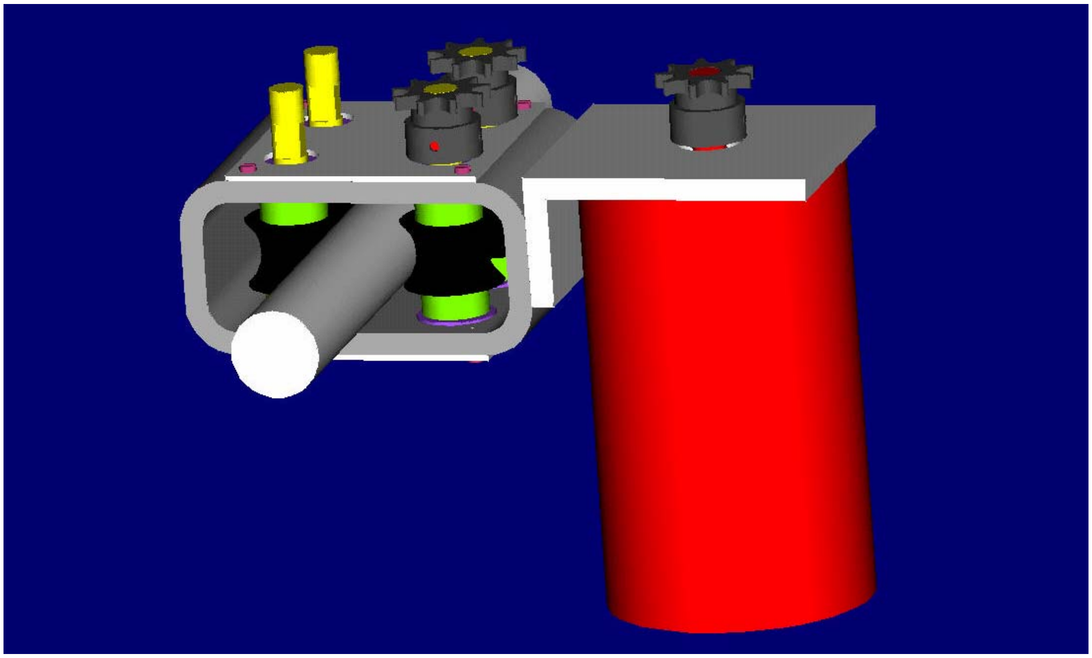

Figure 11.14. Assembly View.

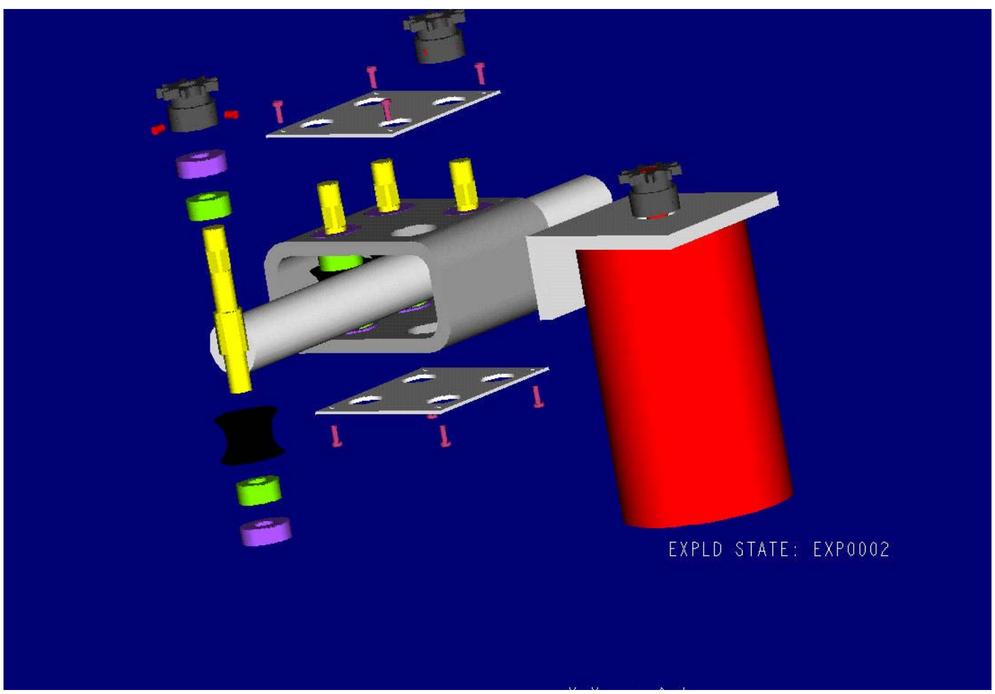

Figure 11.15. Exploded View.