Considering disabled people in sailing yacht design

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ABSTRACT: The paper discusses the design requirements for development of sailing yachts adapted to disabled people. A large percentage of the population has some kind of limitation, either in terms of mobility, sensorial, or intellectual. In general these limitations prevent the practice of sailing sport because the vessels are not adapted to deal with the limitations. This paper starts by identifying and categorizing the disabilities and the consequences on the sailing activity. Then a list of design requirements is established and a procedure is recommended to include these requirements into the design of a sailing yacht. The second part presents the development of the layout design for a 10m sailing yacht taking for disabled sailors.

1 INTRODUCTION

Sailing is a popular activity worldwide, some people practice it as a sport others for pleasure and disabled people may often use it for their personal development. Unfortunately, conventional yachts are usually designed for the middle age male population, most of the times not even suitable for women, young and old people. Here is the starting project of the present paper, based on the concept that all products and environments should be designed to consider the needs of the widest possible array of users. This is called Universal Design, which is a way of thinking about the design that considers human people limitations not as a condition of few but as a common characteristic of all, since we all change physically and intellectually through our lives. If a design works well for people with severe limitations it is expected to work better for everyone. Therefore, the present work is focused on disabilities, which are considered to be the most severe type of human limitations, but the final result is expected to benefit a much larger population.

In comparison with other sports, sailing vessels require little mobility and the controls may be easily adapted to different kinds of operation, these characteristics make sailing a popular activity for disabled population. The majority of boats used by disabled people are small in size and crew, often dinghies commercially produced for this application. These boats solve the mobility problem by seating the sailor in a central position facing the front with all the sails and directional controls within arm reach. The controls are often modular and offer different possible operation according to the user needs. In terms of larger vessels there are only a few individual projects of yachts designed for disabled people and a few other conventional yachts extensively modified for the this purpose. The study of the sailing vessels available for disabled people indicates that they sail mostly single handed and doesn't have the opportunity to be part of a crew. Also, it is not easy for a disabled sailor to leave sheltered waters to do even small coastal passages.

The present paper intends to identify the most important limitations to the integration of disabled people onboard sailing yachts and organise them for easier incorporation in the yacht design process. The safety onboard is also considered here because disabled people often have more difficulties to cope with the situations and face higher risk of injury. This is accounted by a review of the literature published about injuries in conventional cruising yachts, which identifies the most critical areas onboard, the dangerous equipment and the frequent types of injuries. A few comments are also given for particular injuries of disabled people. The presentation of the disabled people needs finish with a review of the vessels designed for disabled people and the respective auxiliary systems, which show how other projects already tried to solve these problems. To illustrate the discussion a case study of a 10 meter yacht designed for disabled people is presented at the end.

2 DISABLED PEOPLE NEEDS

A disability is often associated with several limitations that may change according to the demands of the activity performed, for example a paraplegic sailor may not have a mobility limitation if all the controls are within arm reach. Therefore it is important to identify which are the limitations that common disabilities have regarding the operation of conventional sailing yachts. However, there is little information on disabled people sailing, the most relevant references on the subject are published online by the *Sailability* organisation (*www.sailability.org*) and the *International Foundation for Disabled Sailing* (*www.sailing.org*).

The main limitations to the sail practice are presented in Table 1 according to the respective disability. This classification is based on the previous references and the author's experience with disabled sailors. The disabilities are divided in "*physical*", "*intellectual*", "*sensory"* and "*secondary"*, where the *secondary* group require some considerations but doesn't prevent the practice of sailing. The limitations to the practice of sailing are organised by the authors in "*permanent*", "*non-permanent*" and "*personal*" adaptations, according to how they affect the yacht.

Table 1 intends to make a difference between disabilities and the associated limitations, particularly because intellectual disabilities often suffer from associated physical limitations. For example, people with cerebral palsy often have poor motor coordination. Most physical and intellectual disabilities have problems to cope with the heel angle, often requiring balance aid equipments onboard. Also, people with physical limitations often need mobility aids in particular to go in and out of the boat. People with intellectual and sensory disabilities, have problems to predict the movement of the boom which may lead to injuries.

The directional and sail controls should be intuitive to be understood by people with intellectual limitations. For example, the conventional horizontal rudder tiller changes the boat direction to the opposite way of the tiller, which is difficult to control even by non-disabled people. This system should be substituted by a driving wheel or a vertical tiller operating in the direct way. Electric equipment is most helpful for people with poor motor control, which is a limitation characteristic of some physical and intellectual disabilities. Visual impaired people may also benefit from electric equipment to receive information. It is worth to remember that most disabled people have poor physical performance due to the disability itself or lack of physical activity, requiring light operational systems.

Paraplegic and quadriplegic people don't feel large areas of the body and are susceptible to injuries without notice. Some intellectual disabilities have poor motor control and may also suffer from injuries due to the collision with hard surfaces. These people would benefit from cushions and other body protections. Large and colourful controls might help people to hold equipment or better visualize it.

2.1 *Methodology to consider disabled people in yacht design*

The identification of the most common limitations to the sailing practice is made to simplify the designer work, since then he is not concerned with a group of disabilities but with a group of design requirements. However, a logic procedure must be defined to organise these limitations according to different stages

Table 1 – Most common limitations to the integration of disabled people in sailing yachts.

		Permanent adaptations					Non-permanent adaptations			Personal adaptations	
	Disability	Low heel angle	Balance aids	Mobility aids	High boom	Aid to go onboard	Simple Direction/Sail Controls	Electronic equipment	Low Physical Performance	Body Protected	Large & Colourful Controls
Physical	Paraplegia e Quadriplegia	x	x	x		x		x	x	x	x
	Amputations	x	x	x		x		x			x
Intellectual	Intellectual disability	x			x		x				x
	Acquired Brain Injury	x	x		x		x	x	x	x	x
	Cerebral Palsy	x	x		x	x	x	x	x	x	x
Sensory	Blindness or Visual Impairment				x			x		x	x
	Hearing Impairment				x						
Secondary	Diabetes									x	
	Asthma								x		

of the design process. The idea suggested here is to give an order of importance to the limitations, where the most important limitations are those who affect permanently the yacht, afterwards the limitations that require non-permanent adaptations, until small details are left to consider. Permanent adaptations are considered to be for example a heavy keel to reduce the heel angle or a general arrangement designed for wheelchair operation while the non-permanent adaptations are related with the operational controls and other systems that may be easily changed through the vessel life. The subsequent paragraphs divide the integration of disabled people in a sailing yacht according to three design stages and identify which are the limitations to consider at each stage.

2.1.1 *First design stage – Permanent adaptations*

The first design stage focuses on the adaptations identified in Table 1 to affect permanently the vessel. The heel angle is an uncomfortable characteristic of sailing yachts, because it increases the problems with balance and mobility onboard. Therefore, a major design consideration should be a low heel angle, which affects the hull shape and appendages configuration.

When sailing, most people have balance problems, but the disabled are the most affected generally due to amputations, low trunk stability or poor motor coordination. The hull and appendages should be designed to reduce the three dimensional accelerations and the general arrangement should accept balance equipment, such as chairs, hand rails, etc.

The mobility onboard a sailing yacht is a difficult problem to address because in most cases there is not enough space for conventional mobility aids. This limitation is increased by the heel angle and the three dimensional accelerations applied to the sailors. The easiest way to solve the problem is to place the sailor in a central position facing front with all controls within arm reach, which minimizes the need to move. This was the solution implemented for small dinghies adapted to disabled sailors. However, in a larger yacht the crew must have access to different areas and the previous solution is not suitable. Therefore, the mobility solution must be according to the size of the vessel, the general arrangement and expected heel angle.

The main sail boom swings from one side to the other, above the cockpit and deck and must be high above the heads, since most intellectual disabled or visual impaired people may not predict when it is going to move. Attention should be also given to the main sheet and blocks which should be attached to a position from where they cannot cross the cockpit. A collision of a crew member with one of these equipments may certainly cause a severe injury.

2.1.2 *Second design stage – non-permanent adaptations*

After defining the general arrangement, hull shape and appendage configuration, the directional and sail controls should be considered. All the considerations made in terms of the control systems are non-permanent and may be changed according to the crew needs. Modular solutions are recommended to adjust to the individual requests.

Simple controls are required when the user cannot understand intuitively the system operation or when there is no physical ability to cope with it. Electric devices are often employed because they reduce the physical requests and are able to be operated by a variety of interfaces. However, there are people who benefit from several adaptations, but still wish to sail as a sport and search for intense physical activity. The equilibrium should be found again with modularity, providing for example the possibility to operate the systems manually or with the aid of an electric system.

2.1.3 *Third stage – Personal adaptations*

After the control systems are defined a wide range of small details should be considered. The third design stage continues after the design project and build of the vessel in order to account with the needs of each particular user. This design stage is concerned with personal equipment, for example cushions to protect the user's body, Braille signs, personal grips for equipment holding, etc.

The suggested sequence seems to be the logic procedure to address a large group of problems identified to affect frequently the integration of disabled people. The subsequent section will present a few considerations to avoid the risk of injuries in the general sailing population, which is an alternative way to improve the users' integration.

3 PATTERNS OF INJURY IN SAILING YACHTS

Little literature exists on the causes of injuries with sailing and most of the studies are concerned with high performance athletes, which suffer from specific injuries mostly related with overuse of particular areas of the body. For the normal sailing a relevant study was made on cruising sailors who spend most of the year on offshore cruising yachts (Rouvillian et al, 2007). Figure 1 reports the most frequent places where trauma occur onboard cruising yachts. The deck is the most dangerous area due to the high exposure to the environment and equipment without effective means of protection. The cockpit is more protected than the deck but most of the work is performed here with the associated risk of injury. The companionway is also a critical area because people are moving from one level to another being easy to lose balance or slip and fall. Many reported injuries also occur at the companionway by colliding with moving equipment when coming out of the interior. The kitchen is also worth of safety concerns in particular for the operation of the gimballed stove.

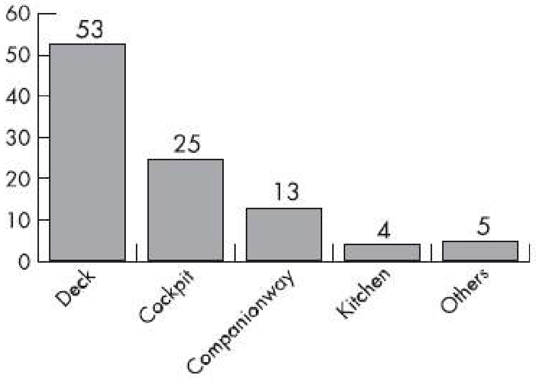

Figure – Risk of injury in cruising yachts [%] (Rouvillian, et al., 2007)

The anatomical regions involved in trauma have been classified by increasing order of frequency as pelvis/abdomen (2%), head/neck (13%), chest (14%), upper limbs (35%) and lower limbs (35%), and these results are similar to those reported from an amateur around the world race, *The British Telecom Round the World Yacht Race 1996-1997* (Prince et al, 2002).

Rouvillian et al. (2007), found that head and neck trauma are often related with a moving spar such as the boom. Accidents typically occur when there is a combination of helm error and jibing while the victim is returning from the cabin, none of them had a companionway sea hood. This is a removable structure placed in front of the cockpit to protect the crew from the sea spray, wind and sun. It seems that this hood forces the sailor to bend down to take the stair case to the cabin which protects effectively from a collision with the boom.

It was found that chest trauma occurs normally when a crew member is carrying an object up to the cockpit. If a rolling motion occurs, the body rotates about a single vertical axis, and the person is unable to grab for support because the hands are occupied. The companionway should be protected by two side walls being much safer than a simple narrow ladder, since the person can lean against a wall to free a hand while keeping three support points.

Hand injuries are generally caused by deck equipment with moving parts and are recommended to protect equipment such as pulleys, winches, windlasses, propellers and motorised deck covers. The lower limb trauma is as common as the upper limb trauma and occurs mostly due to collision with deck hardware. This can be improved with pathways clear from obstructions, with smooth and not slippery surfaces, and by wearing protective foot equipment.

The burns onboard due to solar expose made up 28% of the injuries reported by Rouvilan et al (2007), although most of the crews had been very careful to use sun protection methods. It was in the kitchen that the most severe burns occur. The stove onboard gimballed but it also swings with the motion of the boat, which results in dishes falling off the stove or cooker's body falling into contact with the burning hot stove. The kitchen area should be well designed with handrails available and the cooker should also wear protective equipment while coking at sea.

The occurrence of low back pain in offshore cruisers is most related to the raise of the anchor. All the injuries occur in small boats without windlass and all traumas were sustained when the subject was pulling while standing upright, with full weight of the chain being held by the lumbar spine. If a windlass is not available, it is suggested that the sailor should change to a sitting position on deck with feet resting safely on the pulpit. The lower back pain can be also associated with poor positioning in repetitive motions like trimming sails or lifting objects like spinnaker poles or heavy sails (Allen, et al., 2006).

Even more limited studies have been performed on injuries related with disabled sailors, but preliminary studies suggest that they suffer from injuries similar to able-bodied people (Allen, et al., 2006). In 1999 a survey of disabled sailors during the *International Foundation for Disabled Sailing World Championship*, with 24 teams and multiple disabilities types, showed that the majority of the injuries were chronic in nature (68%) with sprains and strains being the most frequent types of injury. The crew members were at greatest risk of injury (96%) in three person class, with equal distribution between the fore-deck and mid-deck positions. The upper limbs were the most frequently injured body region (60%), likely due to an increased reliance on the upper limbs as a consequence of lower limb or spinal cord disability (Neville, et al., 2009). When performing actions onboard it is important that disabled people without trunk stability have means to support themselves, otherwise one hand will be working while the other is holding the position, increasing much the physical efforts in the upper extremities.

4 EXISTING VESSELS FOR DISABLED PEOPLE

The majority of boats used by disabled people are small in size and crew. Most of them solve the mobility problem by seating the sailor in a central position facing the front with all the sails and directional controls within arm reach. The control systems of the sails and rudder are simple and often compatible with electric devices. The most relevant projects for disabled sailors will be now described.

The Access Company is the largest builder of sailing vessels for disabled people, these vessels search for a balance between recreation, competition and therapeutic activities at a low price. Designed for one or two sailors, the Access dinghies have light and simple operative systems. The stability is provided by a heavy centreboard and wide beam. The high freeboard and the wide deck intend to keep the boat dry when heeling, which is important for sailors that easily suffer from hypothermia. The disadvantage of the high freeboard and wide deck is a possible loss of view to windward when heeling. Nowadays more than 1200 Access dinghies are sailed in fifteen countries and its popularity is increasing considerably. There are a few more dinghies designed for disabled people, namely the Challenger, 2.4M, Artemis 20 and Martin 16, but all of them solve the mobility and balance problems by seating the sailor in a fixed central position.

In terms of larger vessels there are only a few individual projects. A recent one from the University of S. Paulo designed a day-sailer yacht for disabled people (Simos, 2007). The POLI19' has a simple deck layout to leave open the possibility to insert personal adaptations. This creates a flexible base for future personalisation, while a rigid layout would restrict the vessel to some particular type of limitations. The boom is relatively high when comparing with similar boats to avoid head injuries. The POLI 19' has a large cockpit with length approximately 55% of the length overall to avoid the need to leave the cockpit to the forward deck. It has two seats at different heights with an inclination angle relative to the horizontal to support people with balance problems while sailing with heeling angle. The stern is open and has a small platform for easy access to the water and recover a man over board.

The *Veritas K* is another interesting project this time of an ocean going vessel that considers the possibility to be wheelchair accessible (www.*disabledsailing*.org). It has a centre cockpit which protects the crew from the sea spray and gives a clear view all around. All the systems are controlled from the cockpit, which space for wheelchair operation. The entry to the cabin is via a stairway or a wheelchair lift platform and when not in use, the platform lies flush on the cabin sole and does not encumber safe access to the cabin by able-bodied crew members. The saloon also has space for wheelchair operation and access to all the equipment. The Figure 2 shows the interface between the vessel and shore made by the side, where a gangplank concealed in the hull comes out to allow a section of the hull and deck to roll out, giving easy access to the cockpit for anybody including wheelchairs users.

Figure 2 – *Veritas K* with lateral entrance open (*www.disabledsailing.org*).

The catamaran configuration helps the integration of disabled people because of the low heel angle and the spacious cockpit, suitable for wheelchair operation. A good example is the *Impossible Dream,* an 18 meters length ocean going catamaran wheelchair accessible (*www.impossibledream.org.uk*). It has a flat and wide deck to allow wheelchair users to go all around the boat and there is extensive use of rails on deck and inside the cabin. The *Impossible Dream* has three navigation stations, one inside the cabin and one at each side of the deck. From here it is possible to steer the boat, control the sails, engines and operate all the electric devices such as autopilot, GPS, Plotter, etc. For comfort while skippering the boat, there are two chairs inside the cabin fixed to a rail system. The interior is also wheelchair accessible, with access to kitchen equipment and bathroom, a lift platform provides the access to the compartments under deck.

4.1 *Modern adaptive systems*

A wide range of equipment adaptations have already been developed to cope with disabled people limitations, in particular for the Paralympic classes where numerous athletes improve their performance by adapting the material to their needs. Some of these interesting adaptations are provided at the *International Foundation for Disabled Sailing* web site (www.sailing.org). Afterwards attention is given to the recently developed electric equipment.

The design team of the Martin 16 dinghy developed an interesting seat for yachts helm position, which allows people with mobility and balance problems to steer the vessel comfortably for long periods of time. This system, presented in Figure 3, is designed to provide an ergonomic and secure seating for people with or without disability (*www.martin16.com*). The seat travels from one tack to the other, rotating through 180 degrees, allowing the sailor to adopt the conventional position facing the sails or the front of the boat. To accommodate the heel of the boat it tilts 25 degrees forward and aft and can slide up to 8 inches towards the driving wheel, adapting to personal limitations and comfort. A four point safety harness secures and maintains the balance of the sailor in a seaway.

Figure 3 – Six –way Power helm seat (*www.martin16.com*).

The same group also developed a complete set of electric adaptations to operate small vessels (www.martin16.com). This system does the interface between the major controls of the boat and a people with severe limitations. The main part of the system is a joystick module, which contains the main computer and a joystick control. The left and right axis of the joystick operates the helm drive motor to steer the boat, while the forward and backward axis of the joystick operates a windlass to trim the sails. The joystick module can control up to three motors and operate several trimming lines. Other way to control this system is with the sip and puff module presented in Figure 4, which provides a sensitive pneumatic control interface, to allow high-quadriplegic sailors to control the system functions with their breath. The sip and puff interface is a chest mounted control "stalk" with two pneumatic straws within reach of the sailor's lips, one to control the helm and one to control the windlass.

Figure 4. Sip and puff interface (*www.martin16.com*).

The development of electronic equipment is an important improvement for the sailing adaptability. A range of different interfaces between the user and a control motor already exist. It is relevant to consider that a quadriplegic person, for example, is limited in most daily life activities and with an interface like the sip and puff system he or she may go to the water and enjoy a sailing day.

5 CASE STUDY – *INCLUSION 32*

The ideas previously discussed are going to be illustrated with the *Inclusion 32* project. This is a 10 m cruising yacht capable of costal passages designed for disabled people and people who feel conventional yachts difficult to cope with. It has all the facilities necessary for a crew of four people to live onboard a few days, including the galley and toilet designed to be disabled friendly. The Table 2 presents the *Inclusion 32* main dimensions while the Figure 5 presents the general arrangement.

Table 2. *Inclusion 32main dimensions.*

Displacement	6400	kg
Ballast	3400	kg
L_{OA}	9.8	m
L_{WL}	9.1	m
B_{MAX}	3.6	m
Draft	1.8	m
Sail area	42.7	m^2

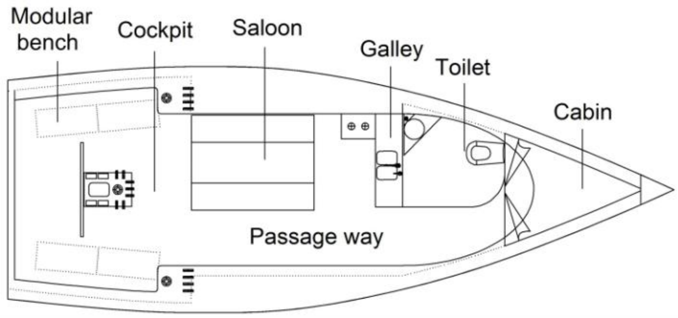

Figure 5. *Inclusion 32* general arrangement.

The design process of the *Inclusion 32* started with the definition of a disabled friendly general arrangement and iteratively searched for a balance between the interior demands and an efficient hull shape. Then, defined the appendage configuration and concluded with the performance prediction. The solutions applied to the *Inclusion 32* for the integration of disabled people are going to be discussed according to the limitations identified in Table 1.

5.1 *Mobility*

The mobility onboard is simplified by a single sole level, common to the interior and cockpit and similar to a sport yacht. It is decided to have a single sole level to avoid the use of the unsafe ladders or lifting platforms, which are not suitable for the wide disabled population. In addition, it is decided to accept wheelchairs onboard because most disabled people are familiar with its operation and the interface with shore is easier. However, to accept wheelchairs onboard it is necessary to have a general arrangement with specific dimensions normally larger than usual, defined according to dimensions advised by the Universal Design architecture (Goldsmith, 2000). Figure 6 presents the pathways available for wheelchair users.

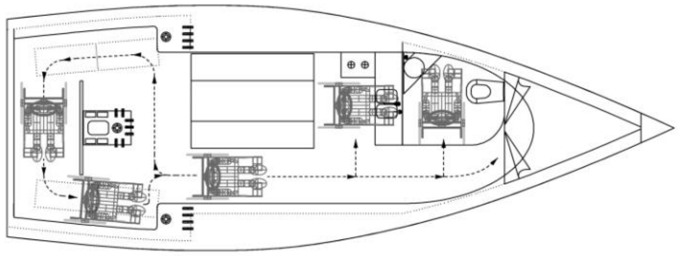

Figure 6. Pathways for wheelchair users at the single sole.

5.2 *Heel angle*

The second design requirement for the integration of disabled people is low heel angle. For the present project the maximum heel angle for the normal sailing conditions is 10^0 which is assumed to be the wheelchairs limit operation, for wind speeds above 15 knots the crew should start reefing the sails. This is guaranteed by the hull shape and appendages design. The hull shape is designed with large waterline beam to increase the form stability, which is the major stability component at low heel angles. In terms of the appendages it is necessary to find a balance between a low sail area and a heavy keel. The *Inclusion 32* is designed with a conventional sail planform, the sail area and aspect ratio are slightly lower than conventional yachts of this size to reduce the heeling demands, but the external appearance is of a conventional cruiser. In addition, it is always possible to reef the sails as the wind increases. The "good looking" sail plan is balanced by the unseen heavy keel and bulb designed according to the results of a purposed developed Velocity Prediction Program made to cope with the limit heel angle.

5.3 *Drive and sails controls*

The steering is made with a driving wheel because it requires less physical effort and has a direct operation. The steering position is at the lateral extents of the cockpit to give a clear view to the front by the side of the cabin top. Wheelchair users should be positioned facing front because they often have difficulty to twist the trunk and neck.

The *Inclusion 32* has a mainsail, a self tacking jib and an asymmetric spinnaker, all with furling systems and controlled from the cockpit. The sails operation is the most physically demanding task and the sails control areas are designed to promote ergonomic postures (MacLeod, 2000). As presented in Figure 7 the body is close to the equipment, forces direction is aligned with the body centreline and there is room below the trimming surface for the user legs and wheelchair arm rests in order to provide a closer approach to the equipment. Bellow each trimming area exist a space to store lose ropes in order to reduce mobility obstacles.

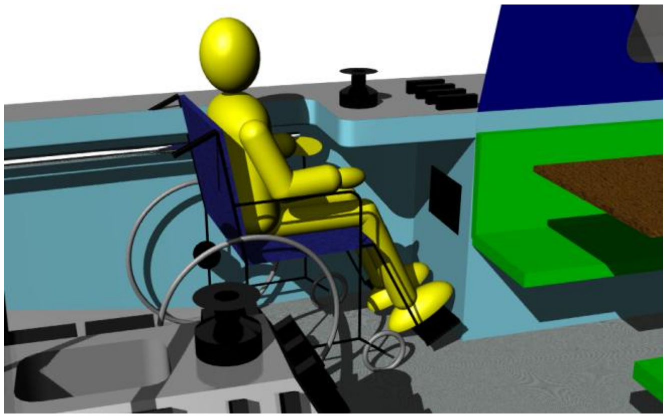

Figure 7. Ergonomic position to trim the forward sails.

5.4 *Modularity*

In order to include wheelchair users and non-wheel chair users in the cockpit a modular solution based on removable benches is designed. These have operation similar with the table of the *Impossible Dream* catamaran present in Figure 8**,** and may be hidden at the sole level to give room for wheelchairs. This is illustrated in Figure 9, the users at the port side use the modular bench which is hidden at the starboard side for wheelchair users.

Figure 8. Table stored at sole level (*www.impossibledream.org*).

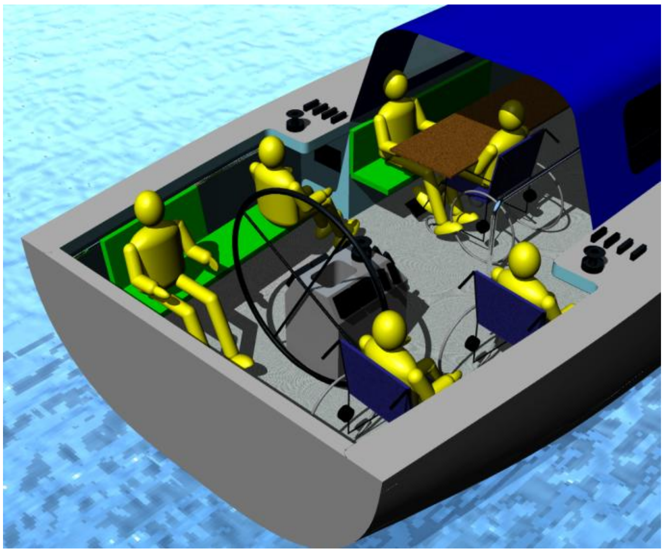

Figure 9. *Inclusion 32* cockpit and saloon view.

The sails can be trimmed manually or by electric winches while the steering is made by the driving wheel or autopilot. The electrical systems can be controlled with different interfaces as described in the adaptive systems section. The *Inclusion* 32 guarantees the integration of a wide range of disabilities with mobility based on wheelchairs and these modular solutions.

5.5 *Social environment*

Most people like to go sailing with friends or family and use it for a social moment. In conventional yachts the saloon is a dark area, lower than the cockpit with a little contact to the exterior. The *Inclusion 32* is designed with a single sole level and the saloon in front of the cockpit to promote the social contact between the saloon users and the crew involved with the sailing tasks, as illustrated in Figure 9. This arrangement is designed to give the opportunity to severely disabled people to go onboard, seat comfortably in the saloon and presence all the activity.

Disabled people often have problems with communication either due to sensory limitations or difficulty to twist the trunk to face someone, therefore it is decided to use an electric engine which has a silent operation. In addition the energy stored at the batteries bank may be used to operate the electric adaptive systems.

5.6 *Injury prevent*

The most frequent injuries onboard sailing yachts were previously identified and the preventive considerations taken applied to the *Inclusion 32* are now summarised. The single sole level common to the cockpit and cabin avoids the risk of injuries related with the companion ladder. The need to go up to the deck in adverse weather conditions is reduced since the yacht operation can be performed entirely from the cockpit. An extensive use of handrails is made to support the crew balance while sailing. The main boom is designed well above the average people height and the associated equipment is attached at the cabin top. The anchor is operated by an electric windlass at the bow, avoiding the back stress associated with pulling the anchor.

6 CONCLUSIONS

The present paper uses the Universal Design concept to include a wide range of abilities in sailing boats. The study is focused on the most severe human limitations often associated with disabilities.

The most important limitations to the sail practice are identified and organized according to an order of importance, where the most important limitations affect more permanently the yacht and should be considered at the initial stages of the design process. Therefore, the first design stage should found suitable solutions for the heel angle, balance and mobility problems. Afterwards, the directional and sails controls should be studied; these are non-permanent characteristics and may change according to the user needs. It would be a good practice to consider at this stage a few modular solutions. The third design stage continues after the end of the yacht design process, as it defines the adaptations required for specific users. In addition to this procedure a few considerations in terms of injury prevention should be taken to improve the overall safety of the project.

The case study illustrate that with simple considerations it is possible to increase the sailing population. Furthermore, the decisions taken to include disabled people are found to improve the comfort of non-disabled as well.

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