INTRODUCTION

A large percentage of the population has some kind of physical or mental limitation, either due to disease, accident or old age. Even though, conventional yachts are still focused on the middle-age male population. Here is the starting point of the present project, based on the concept that all products and environments should be designed to consider the needs of the widest array of users. This is called Universal Design, a way of thinking about design that considers human limitations not 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 project was focused on disabilities, which are considered to be the most severe type of human limitations but the final result is expected to include a larger population. This way of thinking is often defined as inclusive, for that reason the result of the present work will be baptized as “Inclusion”.

The present project requires a combination of naval architecture with disabled people knowledge. However, the problem of disabled people sailing is difficult to address with a theoretical approach because there is little literature on the subject. From the beginning of the project was necessary to have personal contact with disabled sailors in order to identify their main limitations and only then use naval architecture to solve them. To do so, the author worked for a year as coach of the Clube Naval de Cascais disabled sailing team and was responsible for the first Portuguese team going to an Access World Championship. This was an important experience for development of the present work and gave to the author an additional motivation for the success of the Inclusion project.

The project main idea was to support disabled sailors in their quest for independence and the direction of the work was decided by the disabled sailors wish and the author’s opinion about what is needed. A review of disabled friendly sailing vessels indicated that disabled people sail mostly single handed and it not possible to leave sheltered waters to do even small passages. Therefore, it was concluded that a cruising vessel designed for coastal navigation was needed, with habitability for a small crew with different disabilities to live onboard for a few days. The mono-hull was the chosen hull type because the initial and maintenance costs are considerably lower than a catamaran. In addition, the majority of sailing vessels are mono-hulls and was interesting to develop inspiring ideas for better integration of disabled people in future projects. The maximum length of the project was defined to be 10 m according to the rates applied in Portuguese marinas. The design procedure developed for the Inclusion project is going to be subsequently presented. Afterwards, each stage is discussed individually with the respective design decisions.
2 DESIGN PROCEDURE FOR THE INCLUSION OF DISABLED PEOPLE IN YACHT DESIGN

The design procedure developed for the Inclusion 32 is illustrated in Figure 1. The central part of the process was the identification of disabled people needs, entitled as Universal Design. This investigation identified the most frequent limitations to the sailing practice to be mobility, heel angle and safety, and these were solved by specific stages of the design process.

Conventional yacht design process usually starts with the definition of the hull shape because the velocity performance is a major concern. In contrast, the present procedure starts from the general arrangement to solve mobility and safety needs. The mobility solution will define the internal volume and maximum heel angle. Only then should be considered the hull shape and the sailing performance should be optimized within the interior volume and heeling angle requirements. Afterwards, the sails and underwater appendages are designed to achieve the heel angle limitation. The optimization of the hull shape and appendages for the given heel angle was made with a Velocity Prediction Program developed and validated for the present project. The structural arrangement was then designed to comply with the safety needs and the previously defined general arrangement, hull shape and appendage configuration. The design process was an iterative procedure until the three initial design requirements are fulfilled. The considerations applied to each of these stages during the Inclusion 32 project will be subsequently presented.

3 DISABLED PEOPLE NEEDS

3.1 Universal Design

The present work intends to apply the Universal Design concept to the project of a small cruising yacht accessible to a population with a wide range of abilities. The idea was to design an inclusive environment focused on the main human limitations, usually defined as disabilities, to create a better yacht for everyone, in particular women, old and young people that often find difficult to cope with conventional yachts.

The most important limitations to the integration of disabled people in conventional yachts were identified and organized according to an order of importance, where the most important limitations affect more permanently the yacht and should be considered from the initial stages of the design process. Therefore, it was decided to start the design process aiming for suitable solutions for the mobility heel angle and safety. 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 to adapt to the individual needs. The third design stage continues after the end of the yacht design process, as it defines the adaptations required for specific users.

An investigation on the Universal Design architecture defined the physical dimensions suitable for wheelchair operation, accessible toilet and heights of equipment suitable for the average population [2]. A practical view of the problem was given by a review of the sailing vessels most used by disabled people and the respective adaptive systems. Presently, most disabled friendly boats are dinghies and solve the mobility problem by seating the sailor in a central position facing front with the sails and directional controls within arm reach.

The previous considerations defined the needs of disabled people and provide a solid base for the understanding of the decisions taken through the design process. The three major concerns for the integration of disabled people are subsequently discussed.

3.2 Mobility

Mobility was a difficult problem to address because conventional yachts do not have space for conventional mobility aids. In addition, the interior, cockpit and deck are normally at different heights. Even though, there is only one concept of mono-hull sailing yacht and all look very similar.

The present project decided to integrate wheelchairs onboard, because they are widely used by people with mobility limitations. This provides comfort and independence for those used to operate it in
daily life. The operations between the vessel and shore are also simplified because the mobility aid is the same. The wheelchairs operation requires flat sole surfaces free from obstructions. Other mobility concern was to eliminate the need of lifting devices, such as ladders or lifting platforms, because they are not accessible to a wide population; for example a paraplegic may benefit from an electric lifting platform but an intellectual disabled may not understand its operation. The interior dimensions were designed according to the dimensions advised from the Universal Design architecture [2] in order to guarantee wheelchair accessibility.

3.3 Heel angle
The heel angle is an unavoidable characteristic of mono-hull yachts that affect negatively the mobility and balance while sailing. The heel angle should be minimized at least for values acceptable for wheelchair operation, defined according to the inclination of wheelchair accessible ramps advised by Universal Design architecture [2]. Therefore, the Inclusion 32 was designed for a maximum heel angle of 10° for wind speeds below 15 knots and no reefing of the sails. An alternative system is proposed at the end of the present report to reduce the heel angle and self balance the yacht according to the wind demands.

3.4 Safety
The safety was an important concern because disabled people have additional difficulties to cope with the sailing tasks and suffer from higher risk of injury. Therefore, a study on the frequent injuries related with amateur and disabled sailors was performed. The most critical areas on cruising yachts were identified in decreasing order as deck, cockpit and companion way [1]. Through the design project injury preventive considerations were applied to increase the overall safety of the project. The structure was designed to withstand damaging situations common for inexperienced crews. In case of collision with another vessel or floating object the Inclusion 32 has a safe structural arrangement.

4 DESIGN PROCESS
The previous considerations identified the specific needs of disabled people, which are the central part of the present project design process, as illustrated in Figure 1. The considerations taken through the design stages are subsequently presented and the final result is evaluated in terms of performance prediction.

4.1 General arrangement
The Inclusion 32 general arrangement was designed to be wheelchair accessible and avoid lifting equipment. Therefore, it has a single sole and all areas at the same level, similar to a sport yacht, but with all the equipment required for a small crew to live onboard for a few days.

Figure 2 illustrates the Inclusion 32 general arrangement from a top view; the human models are positioned to illustrate the dimensions of specific ar-

![Figure 2. Inclusion 32 plan view, with reference to the main areas (no cabin top).](Image)
The entry to the vessel for wheelchair users is made by the transom panel, as illustrated in Figure 3.

Figure 3. Entry from a side pontoon.

The sailing area was positioned at the stern where the drive and sails controls are located. The directional control is made by a driving wheel, while the sails are controlled at a central station in front of the driving wheel and by the sides of the cabin top. The cockpit has two modular seats at each side to be used by non-wheelchair users while steering or trimming the sails. These seats were designed to be hidden at the sole level to give room for wheelchair users, as illustrated in Figure 4. The central station controls the halyards and main sheet, while the lateral areas trim the forward sails sheets and other lines that require constant operation.

Figure 4. Modular cockpit, suitable for wheelchair users and non-wheelchair users.

Figure 5 is a lateral view from the Hallberg Rassy 31 [3] presented to illustrate that conventional yachts have a dark saloon inside the vessel, isolated from the environment and crew. In contrast, Figure 6 presents the Inclusion 32 with the saloon designed to be the continuation of the sailing area, which gives to the saloon users a feeling of integration with the crew. This configuration was designed to accept very disabled people onboard, because if someone doesn’t have ability to cope with the sailing tasks he may seat comfortably in the saloon and presence all the activity, as well as communicate with the rest of the crew and enjoy a day of sailing. The saloon is protected from the wind, sun and sea spray by the cabin top, still in contact with the environment by the large windows. In addition, the saloon was designed to be a dormitory in harbours or while sailing at night, the table is lowered to the seats level to form a bed for two people. The Inclusion 32 operates an electric engine because it has a silent operation which minimises the communication problems.

Figure 5. Hallberg Rassy 32 lateral view [3].

Figure 6. Inclusion 32 lateral view.

The galley was designed out of the passage way between the sailing area and the other compartments in order to avoid permanent mobility obstructions between the crew elements. There are two cutting surfaces, a double sink, a fridge placed at the corner and a gimbaled stove by the side. A continues hand-rail was placed along the entire galley to support the cooker while sailing.

The toilet was designed according to the Universal Design architecture to be particularly well acces-
sible [2], which required an area larger than usual. The cabin is at the bow with a 2m long bed for two people, closed by a curtain.

The previous considerations presented the general arrangement in terms of the mobility problem, in terms of safety the Inclusion 32 has a single sole level common to the cockpit and the cabin, which avoids the risk of injuries related with the companion ladder. The need to go up to the deck in adverse weather conditions is also reduced since the yacht can be entirely controlled from the cockpit. Extensive use of hand rails was made to support mobility in seaway. The boom was designed well above the average people height and the respective sheet was attached to the cabin top clear from the crew. The lateral trimming areas were designed according to human statistical dimensions [2] to promote ergonomic postures, as illustrated in Figure 7. The sailor is facing the front of the yacht to avoid trunk torsions and the controls are placed at a correct height, aligned with the body centreline. The anchor is operated by an electric windlass at the bow to avoid the back stress associated with pulling the anchor.

Figure 7. The cockpit layout was designed to promote ergonomic postures.

The general arrangement was designed to be wheelchair accessible; however the wheelchairs operation still require low heel angle subsequently considered by the hull shape and appendage design.

4.2 Hull shape

The Inclusion 32 hull shape was designed to provide the internal volume required by the general arrangement and increase the form stability, which is the major stability component at low angles of heel. In order to evaluate the present project dimensions was made a data base of modern cruising yachts with size from 9 to 11 m. Table 1 presents the Inclusion 32 main dimensions in the form of dimensionless ratios and compare these values with the average, maximum and minimum results obtained from the data base.

<table>
<thead>
<tr>
<th></th>
<th>Inclusion 32</th>
<th>Average</th>
<th>Max.</th>
<th>Min.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loa/Bmax</td>
<td>2.72</td>
<td>2.91</td>
<td>3.07</td>
<td>2.75</td>
</tr>
<tr>
<td>LWL/T</td>
<td>4.86</td>
<td>4.83</td>
<td>5.14</td>
<td>4.54</td>
</tr>
<tr>
<td>Bmax/T</td>
<td>1.95</td>
<td>1.85</td>
<td>2.01</td>
<td>1.70</td>
</tr>
<tr>
<td>LW/T</td>
<td>4.85</td>
<td>5.21</td>
<td>5.66</td>
<td>4.63</td>
</tr>
<tr>
<td>Ballast/Disp</td>
<td>0.53</td>
<td>0.32</td>
<td>0.39</td>
<td>0.25</td>
</tr>
</tbody>
</table>

The Inclusion 32 has a $L_{oa}/B_{max}$ slightly lower than the data base minimum value because of the large internal volume required for wheelchair operation. In addition, it is advantageous to have a wide beam because form stability is inversely proportional to $L_{oa}/B_{max}$ ratio.

The present dimensions correspond to the Short Keel version designed for conventional draft, consequently $L_{WL}/T$ and $B_{max}/T$ ratios are within the range of conventional yachts, a Long Keel version will be also designed to improve the sailing performance.

The $L_{WL}/Disp^{1/3}$ is an important ratio to evaluate the yacht performance, in particular at high speeds. According to Table 1 the Inclusion 32 has a $L_{WL}/Disp^{1/3}$ considerably lower than the average but within the limits. The large displacement is due to the heavy bulb designed according to the heel angle requirement; this characteristic is evident from the given Ballast ratio.

The prismatic coefficient ($C_p$) and the position of the longitudinal centre of buoyancy (LCB) influence significantly the residuary resistance of the vessel. Optimum values for these parameters were computed from the formulations presented by the Delft Systematic Yacht Hull Series [4], also used in the Velocity Prediction Program to compute the hydrodynamic resistance. The Inclusion 32 was designed to have optimum performance with medium wind speeds, about 12 knots. The respective optimum $C_p$ is 0.58 while the LCB is 3.5% of the waterline length aft amidships. It was not possible to achieve an optimum LCB because the wheelchair accessible toilet and passageway at the bow moved the LCB to about amidships.

The general arrangement designed an accessible and safe layout for wheelchair operation, while the hull shape was concerned with the required internal volume and form stability. The subsequent stage is the appendage design which continues the aim to minimise the heel angle in what concerns the sails and underwater appendages.

4.3 Appendage design

The easiest way to reduce the heel angle is either to design a reduced sail plan or a heavy keel, and this relation was a critical part of the project. However, the sails affect considerably the outward image of
the vessel, which means that a yacht with proportionally large sails of high aspect ratio looks more attractive than the same hull with smaller sails. The same doesn’t happen with the underwater appendages because they are unseen. Therefore, the Inclusion 32 was designed to have the sail planform of a conventional cruiser balanced by a heavy keel designed to achieve the required heel angle. The sails planform was designed according to the knowledge from wind-tunnel experiments [5] and information collected for the data base of similar yachts. Table 2 compares the present project dimensions with the data base values. The Inclusion 32 was designed with low aspect ratio (AR) sails in order to reduce the sails centre of effort height and the respective heeling moment. In addition, the low aspect ratio sails improves the overall sailing performance in detriment of the upwind sailing. The sails area (A) is slightly smaller than the average to reduce the sail forces and simplify the crew handling.

<table>
<thead>
<tr>
<th>Dimension</th>
<th>Inclusion 32</th>
<th>Average</th>
<th>Maximum</th>
<th>Minimum</th>
</tr>
</thead>
<tbody>
<tr>
<td>A_{main} [m^2]</td>
<td>22.5</td>
<td>23.6</td>
<td>28.2</td>
<td>21.1</td>
</tr>
<tr>
<td>A_{k} [m^2]</td>
<td>20.2</td>
<td>20.8</td>
<td>24.1</td>
<td>14.7</td>
</tr>
<tr>
<td>AR_{M}</td>
<td>5.1</td>
<td>5.5</td>
<td>5.8</td>
<td>4.5</td>
</tr>
<tr>
<td>AR_{L}</td>
<td>5.6</td>
<td>6.7</td>
<td>7.1</td>
<td>6.4</td>
</tr>
</tbody>
</table>

The underwater appendages were designed after the sails because use was made of dimensionless ratios presented in the literature [6] to relate the underwater appendage lateral area with the sails area previously defined. As is often the case of production boats, two keel configurations were designed to have the same initial stability, the Short Keel version was designed to have conventional draft and operate with less restrictions in marinas and shallow waters, while the Long Keel version was designed with higher draft to increase the sailing performance. Both keels were designed with the same lateral surface but the Long Keel version has a higher aspect ratio. The keel lateral area was defined to be 3.5% of the total sail area [6]. The keel taper ratio was defined above the optimum value in order to provide a larger keel tip chord to support the heavy bulb. The keel operates at the leeway angle of attack, usually lower than 5°, where the lift production is about equal within NACA profiles and the keel design goal was to minimize drag. Therefore, it was chosen the NACA 65-015 because the 65-series have lower drag at low angles of attack and the thickness-chord ratio of 15% correspond to the respective series maximum lift production [6], useful for extreme situations like manoeuvring inside the harbour with low speed.

The rudder lateral area was defined to be 1.5% of the total sails area [6] while the sweep angle and the shaft inclination were defined to be perpendicular to the bottom surface, at 15° to the vertical. The rudder operates most of the time at higher angles than the keel and normally corrections to the course are continuously made. Therefore, the flow around the rudder is constantly disturbed and sections that promote laminar flow such as the 65-series are not useful. It was decided to use a NACA 0012 section because the four-digit series produces high lift and the thickness chord ratio of 12% increases the rudder operational angles [6]. The keel bulb was used to increase the transversal stability, since it doesn’t produce any lift the design goal was to minimise drag. The bulb weight was optimized for each keel to cope with the limit heel angle condition with the Velocity Prediction Program made for the present project. The bulb section profile was a NACA 65-021 because the 65-series have low drag at low angles of attack and the thickness chord ratio of 21% minimises the frictional and form drag components for a given bulb volume [7].

The directional stability of a yacht is defined by the longitudinal position of the sail plan in relation to the underwater body. The position of the sails centre of effort is restricted by the mast position defined to be aft the toilet in order to don’t interfere with mobility onboard. The keel was positioned longitudinally in order to locate the underwater centre of lateral resistance at 5% of the waterline length aft the sails centre of effort [6].

4.4 Structural design

As the vessel was designed for disabled people with the associated limitations, it was expected that through its life it may suffer from damaging situations, requiring a solid construction, easy to repair. The materials and construction methods chosen for the Inclusion 32 used low-cost technology and were thought to be built in Portugal. The composite reinforcement was chosen to be E-glass because of the good cost/strength relation. The laminate is build with alternated layers of Woven Roving (WR) and Chopped strand mat (CSM), where the WR support the main loads while the CSM ensure sufficient interlaminar strength [8].

The panel construction was decided to be single skin because it is more solid and easier to repair than sandwich construction. The greatest advantage of sandwich compared to single skin is the increase in strength and stiffness without a corresponding increase of weight. However, due to practical considerations the outer skin cannot be made to thin or else will have insufficient strength to withstand docking, grounding and boatyard handling. This means that the sandwich weight advantages are not evident in yachts below 9m [6]. The construction method was
decided to be hand-layup because it has a better performance/cost relation for the intended use of the vessel.

The structural arrangement was dimensioned to obtain the ISO 12215-5 standard [9] approval and an alternative method presented by The Elements of Boat Strength [10] was used to validate the results obtained from the recently made ISO rules. In addition to the ISO requirements was reinforced the critical areas as well as defined the hull-to-deck joint and the keel bolts.

The height of the internal stiffeners in conventional yachts is limited to don’t interfere with the interior headroom. This was not a problem for the present project and a more efficient structure was designed, where the vertical height of the longitudinal stringers was increased and the conventional ring frames were substituted by watertight bulkheads below the sole level. The Inclusion 32 has structural arrangement close to a double bottom which increases the survivability in case of collision with other vessel or hitting something underwater.

4.5 Inclusion 32 performance analysis

The Inclusion 32 was evaluated in terms of transversal stability, seakeeping and sailing performance. In terms of transversal stability, both keel versions have the same curve of static stability up to 60° of heel and a maximum righting moment of 63.5 kN, the Long Keel version has a slightly larger stability range. Figure 8 is a comparison between the Inclusion 32 and Hallberg Rassy 31 (HR31) curves of static stability. Conventional yachts are usually designed to operate at an average heeling angle of 30° [6], where the HR31 has a righting arm of 21.4 kN.m, which correspond to a heel angle of 12° in the present project. As the Inclusion 32 sail area is lower than the HR31, the inclining moment will be proportionally lower. Therefore, when the HR31 is in normal sailing, with 30° of heel, the present project will be sailing with less than 12°, which is according to the design objective.

The seaworthiness of the present project was evaluated according to the ISO 12217-2 standard, presented by Principles of Yacht Design. The present project Stability Index (STIX) is penalised by the open entrance from the cockpit to the interior, since the first downflooding occurs when sheer line is immersed, at 35° of heel. In a flooding situation, the water will normally leave the cockpit through the stern due to the aft inclination of the sole. If the boat has a large forward trim angle the water will move forward and out of the interior through a pipe connecting the interior to the bottom surface. The operation of the yacht is guaranteed by a reserve of buoyancy of more than twice the normal sailing displacement. The STIX calculation qualified the Inclusion 32 with B, however A and B ratings must have a downflooding angle above 90°, which gives C as the final grade. The class C allows close coastal navigation and is still suitable for the present project.

For further development of the project an analysis of the complete ISO 12217-2 standards is required to evaluate possible considerations to yachts with unusual characteristics.

The Inclusion 32 optimization process used the Velocity Prediction Program (VPP) made for the present project. A VPP solves the mathematical equations of the aerodynamic and hydrodynamic forces until an equilibrium situation is found. Conventional VPPs assume the maximum speed to be the limit situation while disabled crew operation assumes the maximum heel angle. Therefore, a specific VPP was developed and validated with a conventional VPP, PCSAIL 2.5.

Figure 9 presents a diagram of the calculation process and identifies the relevant parameters between each step. To start the calculation process the user specifies the true wind speed (V_{TW}), true wind angle (B_{TW}) and maximum heeling angle (\(\phi_{MAX}\)). The solution algorithm guesses an initial yacht velocity (V_{S}) and heeling angle (\(\phi\)), if the heeling angle is above the maximum a flat coefficient and reef coefficient may be applied to reduce the heeling angle. The flat corresponds to a reduction in the sails lift.

![Figure 8. Curve of static stability.](image-url)
due to a reduction of the sail camber while the reef correspond to a decrease in lift and drag due to a reduction in the sails area. For a given true wind the solution algorithm calculates the apparent wind velocity ($V_{AW}$) and apparent wind angle ($\beta_{AW}$). The aerodynamic drive force ($F_x$) and aerodynamic side force ($F_y$) is computed from the apparent wind and sails pressure coefficients [6]. From the side force is computed the heeling moment which is interpolated in the curve of static stability to obtain the new heeling angle. The drive force, side force and heel angle are required to compute the vessel hydrodynamic resistance, according to the Delft Systematic Yacht Hull Series, which are formulations to estimate the components of the yacht resistance derived from extensive series of tank tests [4]. The new velocity and heel angle are assumed to be the initial guesses for the next loop until the results converge.

The previous program was used to estimate the Inclusion 32 performance with sails trimmed for the maximum velocity and with sails trimmed to cope with the heel angle condition defined for the wheelchair operation. The maximum velocity results were compared with a similar yacht, Hanse 32 [11], concluding that the commercial vessel is 17% faster for true wind speeds of 8 knots and 11% faster for true wind speeds of 14 knots. The differences are higher for close hauled courses and less significant for running courses. These results are satisfactory since the Inclusion 32 performance is restricted by the heavier displacement and the lower sail area, defined to cope with disabled people needs.

When comparing the velocity predicted for the two keel versions, the Long keel is in average 1.5% faster at 5 knots of wind. The Long keel advantage increases with the wind speed and is considerably larger for close hauled courses, decreasing with the true wind angle until the running courses where both keels have the same performance.

An analysis of the hydrodynamic resistance components was performed to identify the physical differences between the two keel versions for close hauled, reaching and running courses. The induced resistance was identified to be the responsible for the velocity difference between the two keel versions. For close hauled courses ($\beta_{TW}=40^\circ$) at 12 knots of wind speed, the induced resistance was predicted in 20.3% for the Long Keel and 28.3% for the Short Keel version in percentage of the total resistance. This was theoretically expected due to the higher efficiency of the high aspect ratio keel. As the true wind angle increases the leeway angle decreases, reducing proportionally the induced resistance percentage of the total resistance and the Long Keel advantage.

When considering the operation of disabled people, it was assumed that at any heading the heel angle should be less than $10^\circ$ for true wind speeds lower than 15 knots, without reefing the sails. This condition was considered when defining the transversal stability of both keel models and verified with the Velocity Prediction Program. Figure 10 presents the velocity predictions for the maximum speed and maximum heel limit conditions. For true wind speeds below 12 knots the velocity predictions for a disabled crew correspond to the maximum values of the respective keel version. For true winds speeds above 12 knots the flat coefficient was used to comply with limit heel angle which affects the velocity performance. For winds speeds above 15 knots the Inclusion 32 performance is considerably reduced indicating that the boat could benefit from reefing the sails. These results guaranteed an acceptable sailing performance.
5 SELF STABILITY SYSTEM

During the development of the present project the heel angle was identified to be one of the main problems for the integration of disabled people. However, the mono-hull yachts need to heel in order to produce form and weight stability and generate drive force. There are a few methods to increase the righting moment, namely the water ballast tanks and canting keels. None of these systems are automatic but require manual or electric control. The manual control of a stability device is only suitable for very experienced crews while the electric control is complex and economically not acceptable for the present project. Therefore, it was interesting to explore alternative ways to change the vessel stability according to the wind demands.

The solution came with a conventional canting keel arrangement operated by the shrouds tension. The system was described numerically and the sequence of formulations was used to predict the heel angle of each component and the respective loads. The main factors involved in the system operation are the angle between the shroud and the mast and the keel lever arm length as well as the sails and keel configuration. The angle between the shrouds and the mast is inversely proportional to the shroud tension which is applied to the keel. As the keel swings the shroud length is extended and the mast has to rotate to leeward, reducing the angle between the shrouds and the mast. A practical problem to overcome is the increase in compressive loads applied in the diagonal direction to the mast base. The complete development and validation of the self stability system was considered to be out of the present project. However the numerical model was implemented in the Velocity Prediction Program to evaluate the performance effect of the self stability system in the Inclusion 32. The preliminary results suggest that it reduces in average 34% of the Inclusion 32 heel angle. The velocity prediction increases about 1% with the self stability system for a given wind speed but if considered that a boat that heel less can support larger sails the velocity improve is significant. The speed increase is also relevant for the present project since the velocity was severely affected by the heavy displacement and large beam.

6 CONCLUSION

A new design procedure was developed for the inclusion of disabled people in sailing yacht design. The central part of the process was concerned with the needs of the most severe human limitations, often disabilities, in order to improve the environment for everyone. The initial design requirements identified mobility, heel angle and safety to be the main problems. The mobility was solved by wheelchair accessibility and a single sole level, without obstructions and lifting devices. Disabled people also benefit from low heel angle and the present project was designed for a maximum heel of 10° for wind speeds up to 15 knots and no reef of the sails. The safety was considered by injury preventive considerations and ergonomic postures at the physical demanding tasks. In addition, the double bottom arrangement
and the watertight bulkheads improved the vessel survivability in case of collision and the reserve of buoyancy below the sole level guarantees the flotation in case of flooding.

The design process started with the general arrangement, designed to be wheelchair accessible according to the dimensions advised by the Universal Design architecture. A modular solution based on removable seats was designed to accommodate wheelchair users and non-wheelchair users in the same space. The saloon was designed to be the cockpit continuation in order to improve the social contact between the saloon users and the crew involved with the sailing tasks. The large windows were designed to promote the contact with the environment.

The hull shape was designed according to the interior volume required by the general arrangement and the large waterline beam increases form stability. The prismatic coefficient is optimum for medium wind conditions while the longitudinal centre of buoyancy is forward the optimum position because of the large volume required for the toilet and pas sageway at the bow.

The appendage design also aimed for low heel angle, achieved by a conventional cruiser sail planform balanced by the unseen heavy bulb keel. The sails characteristics were defined according to a data base made with similar yachts. The keel and rudder were defined according to the sail area and literature data. Two keels were designed with the same lateral area and initial stability, one with conventional draft and the other with higher aspect ratio to minimise the induced resistance. Both keels were positioned longitudinally in relation to the sails planform to guarantee directional stability. The bulb was designed to cope with the limit heel angle with the Velocity Prediction Program.

The structural arrangement was designed to have solid construction, simple to repair and the critical areas were reinforced to withstand damaging situations. The materials and construction methods were designed for low-cost technology, with E-glass reinforcement and single skin hand laminated. The scantlings were defined to obtain the ISO 12215-5 standard approval and validated by an alternative method proposed by The Elements of Boat Strength.

A specific VPP was developed because conventional VPPs calculate the equilibrium condition for the maximum speed while the present project assumes a maximum heel angle to be the limit situation. The Velocity Prediction Program used the Delft Systematic Yacht Hull Series to compute the hydrodynamic resistance and sail pressure coefficients from the literature to compute the aerodynamic forces. This program was also used to predict the performance influence of the self stability system, designed to adapt the righting moment to the wind demands. Further development of the system is needed but the preliminary results indicate a significant heel reduction and speed increase. Further development of the Inclusion project should also concern seakeeping analysis and the view angle from the cockpit since it is partially obstructed by the cabin top.

The Inclusion 32 stability and velocity performance were compared with conventional yachts data and the results provide confidence in the design decisions taken through the design process. Therefore, it is considered that the project objective was achieved, with the development of a small cruising yacht accessible to a wide population.

7 REFERENCES