The High Capacity Expanding Lifeboat HiCEL – Meeting the Modern SAR Challenge

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Synopsis

The Mediterranean migrant crisis has resulted in the highest population displacement since the Second World War. In 2016 alone, over one million made the journey across the sea. Since 2013 over 15,000 have died as a result of this journey. Small vessels such as wooden fishing boats and RIBs are commonly used by smugglers as transport. These are often unseaworthy and filled with numbers of passengers far exceeding their intended capacity.

When failure occurs, rescues are typically conducted by the nearest available vessel. These vessels are often ill-equipped for a large-scale Search and Rescue (SAR) operation making it highly dangerous for all involved. The size and quantity of lifeboats available are often insufficient for the large numbers of people to be rescued; as a result, repeat journeys are required, making the rescue process slow, inefficient and hazardous.

This paper outlines a novel solution to this problem. A concept design is presented for a rapidly expandable lifeboat capable of holding large numbers of passengers, whilst still fitting into the operational envelope of common davits. The unique inflatable design can be deployed quickly from a range of vessels and aeroplanes offering an immediate platform from which disembarkation onto a suitable vessel can be achieved. CONOPS are outlined along with the required capabilities of the design. Drop stitch technology is identified as a viable means of manufacturing the large inflatable platforms.

Finally, the paper discusses an alternative solution, retrofitting existing enclosed lifeboats with the solution to offer a more cost-effective alternative.

Keywords: Search and Rescue, lifeboat concept design, survival craft, drop stitch

Abbreviations:

CEP – Combined Expansion Platform
CONOPS – Concept of Operations
COTS – Commercial Off the Shelf
EP – Expansion Platform
FBD – Free Body Diagram
HiCEL – High Capacity Expanding Lifeboat
IMO – International Maritime Organisation
LSA – Life Saving Appliance
MOSHIP – Mother Ship
PEP – Primary Expansion Platform
RCC – Rescue Coordination Centre
RIB – Rigid Inflatable Boat
ROM – Rough Order of Magnitude
SAR – Search and Rescue
SEP – Secondary Expansion Platform
SOLAS – Safety of Life at Sea
SUP – Stand Up Paddleboard

1 Introduction

Mass immigration has been a common occurrence wherever there has been war. During the Vietnam war, thousands of Vietnamese people fled the war-torn country using the South China Sea as a popular escape route (United Nations High Commisioner for Refugees, 2000). In recent years mass immigration has made its way back into the headlines, with the development of the European refugee crisis. By the end of 2017 nearly two million refugees have fled civil war in the Middle East. The majority have used the Mediterranean and Aegean Sea to make their way to the relative sanctuary of Europe (United Nations High Commissioner for Refugees, 2018). The

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migrant crafts used are typically over-filled and inadequate for the journey making rescue from the migrant crafts commonplace.

Rescue attempts can be dangerous for all involved. In the Mediterranean merchant vessels are often the first to respond but ill-equipped to complete large-scale rescues (ECSA, 2017). Naval and merchant vessels are regularly diverted by Rescue Co-ordination Centres (RCCs) as first responders. In 2016 despite a decrease in rescues, over 300 merchant vessels were diverted to assist with Search and Rescue (SAR) operations within the Mediterranean. Numerous incidents demonstrate the strain these rescue efforts can impose on a ship’s crew. In 2017 an Italian Coastguard vessel supported by the Deep Vision survey vessel rescued 650 people from 6 migrant craft in 5 hours. The commercial vessel was closest to the rescue datum and arrived first. It was however only designed to accommodate 70 people and struggled with the number of people to be rescued (Dearden, 2017). Both vessels deployed their rescue boats with all passengers ultimately transferred to the coast guard ship for return to an Italian port. As demonstrated a multi-ship effort is often required to respond to call outs with merchant and naval vessels most commonly used (NSA, 2014). This prevents the vessels from completing their standing commitments and can prove to be costly for their owners.

Evacuation is widely considered to be a last resort. The recovery of survivors from the sea offers a unique set of challenges, posing risks to both the motherships’ (MOSHIP) personnel and the evacuees. In an ideal rescue scenario, the evacuation would occur within range of a SAR vessel. In reality however, this is often not the case. Despite the efforts of both government and non-governmental bodies it is likely there will always be a requirement for other vessels to respond to emergency situations.

In response to these challenges a novel solution has been developed for a High Capacity Expanding Lifeboat (HiCEL). The design delivers a solution capable of rescuing 500 people from the sea at once and can be used independently of a merchant or naval vessel. HiCEL can be used for both survival and rescue purposes and is deployable in stages to provide an increasing capacity from 50 up to 500 people.

From market research and analysis of typical rescue scenarios the following requirements were identified:

- A safe working capacity of 500 passengers
- A capability to launch from industry standard davits both quickly and safely
- The ability to self-propel, with a maximum transit of 50 miles (it is assumed there will be assistance from other vessels in the area, and that this lifeboat will act as an interim vessel, keeping passengers safe, out of the water)
- Operable in a sea temperature range of 0 – 35 ^{0}C, and sea states of up to 4
- Initial medical capability to provide first response medical attention to evacuees.

2 Design Overview

Achieving a full complement of 500 survivors inside a relatively small operating envelope requires the conventional lifeboat design to be radically rethought. As a result, HiCEL has been designed to incorporate several notable features. An indicative design is shown in Figure 1.

Figure 1 - Indicative concept of HiCEL

2.1 The ability to expand complement dependent on the rescue scenario

The design consists of two main features: a central, rigid hull lifeboat, and a large inflatable area known as the Combined Expansion Platform (CEP). The CEP is stored in three sections, the Primary Expansion Platform (PEP), stored at the stern, and two Secondary Expansion Platforms (SEPs) stored along the length of the lifeboat one port and one starboard. The lifeboat can be used with each expansion either deployed or stowed as depicted in Figure 2.

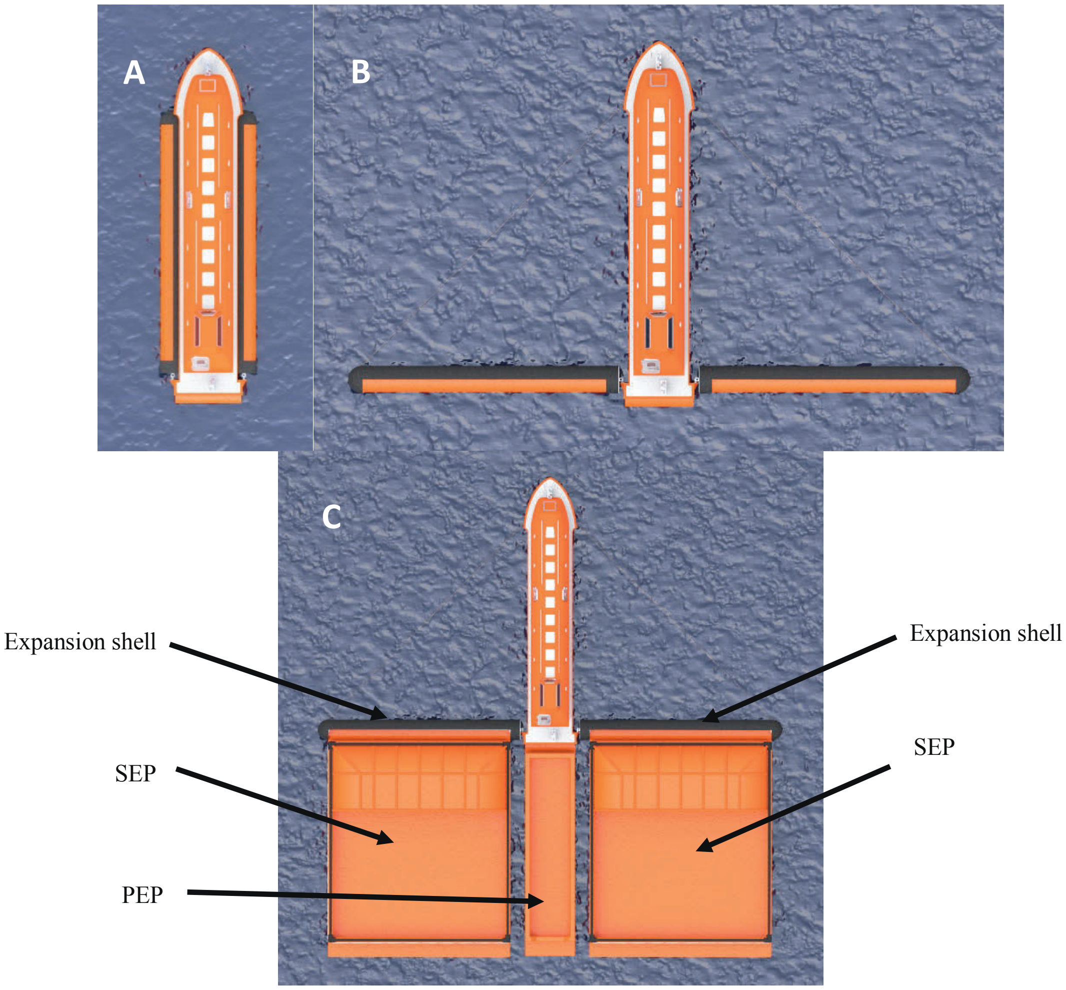

Figure 2 - CEP deployment process, A – pre-deployment, B – expansion shells in position, C – EPs unrolled and inflated

2.2 Deployable from common lifeboat davits

Up until the recent introduction of the lifeboats such as the CRV55 catamaran, lifeboats have followed a conventional monohulled design and have been limited to 150 people. The CRV55 weighs 16T with a beam of 5.6m and has an operational envelope which is significantly larger than conventional lifeboats. Its hull form and large capacity of 370 requires a purpose-built davit and large envelope from which to launch (gCaptain, 2010). HiCEL however does not have this limitation. Like conventional lifeboats, the system is designed to be launched by either a cantilevered platform or gravity davit system. The hook distance of 11.2m allows it to be launched by an industry available davit (NORSAFE, 2018). A reduction of the on-board capacity of the central or main hull, could reduce this envelope further to allow launch from other davits.

2.3 Large platform area with a small stowed volume

Having a large surface area ensures the lifeboat can hold 500 passengers and is the result of a manufacturing technique known as drop stitching. The method uses drop yarn, woven between two skins which when inflated become pre-tensioned, as shown in Figure 3. A unique characteristic of drop stitched fabrics is that the inflated panels demonstrate a high level of rigidity (Hluton, Cavallaro, & Hart, 2017). The technology is now commonly used within the marine leisure market. HiCEL adopts this manufacturing technique with each of its EPs, providing a safe stable platform for all passengers.

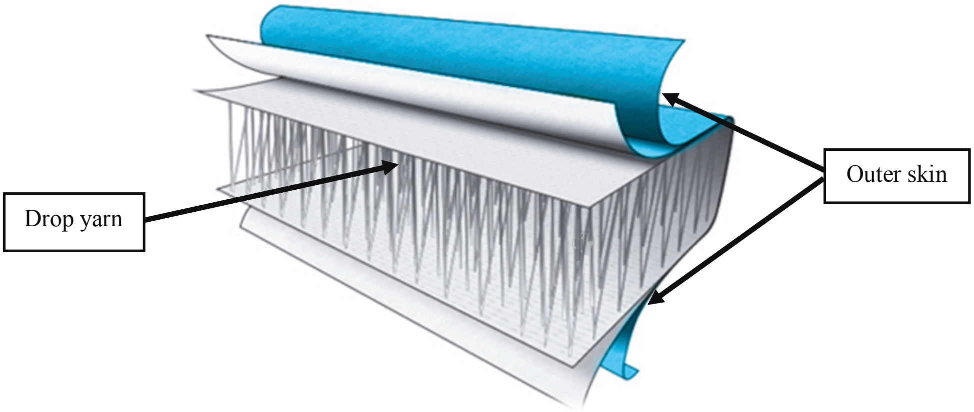

Figure 3 - Internal arrangement of drop stitch fabric

2.4 Specification

The principal dimensions are driven primarily by the spacing requirements. Minimum seating requirements per person are determined by SOLAS International Life Saving Appliance Code (LSA) (IMO, 1998). The resulting principal dimensions are shown in Table 1.

Table 1 - Principal dimensions of HiCEL

	Pre-deployment	Post-deployment
Length (m)	13	24
Beam (m)	4	24.1
Draft (m)	0.82	0.82

The specification of HiCEL is shown in Table 2. The design addresses the power requirements set by SOLAS and the European Council Directive 2014/90/EU on Marine Equipment.

Table 2 - HiCEL specification

Hullform	Monohull
Hull material	GRP
Power Generation	Diesel Compression Engine
Engine Type	Inboard diesel
Engine size	60 KW
Maximum speed	6 kts
Maximum speed (Full deployed)	2 kts
Total Mass (unmanned)	10468 kg
Total Mass (full complement)	52968 kg

Figure 4 shows the general arrangement of the HiCEL. The wheelhouse is in an elevated position with windows on all sides. There is seating for up to 32 persons or provision for up to 8 marine rescue stretchers. There is also space available for storage underneath seats providing the necessary SOLAS emergency provisions. Each seat is provided with a four-point safety harness (IMO, 1998) with additional harnesses to secure stretchers. Evacuation is achieved via the port and starboard access doors, along with emergency hatches at the forward and aft ends of the superstructure.

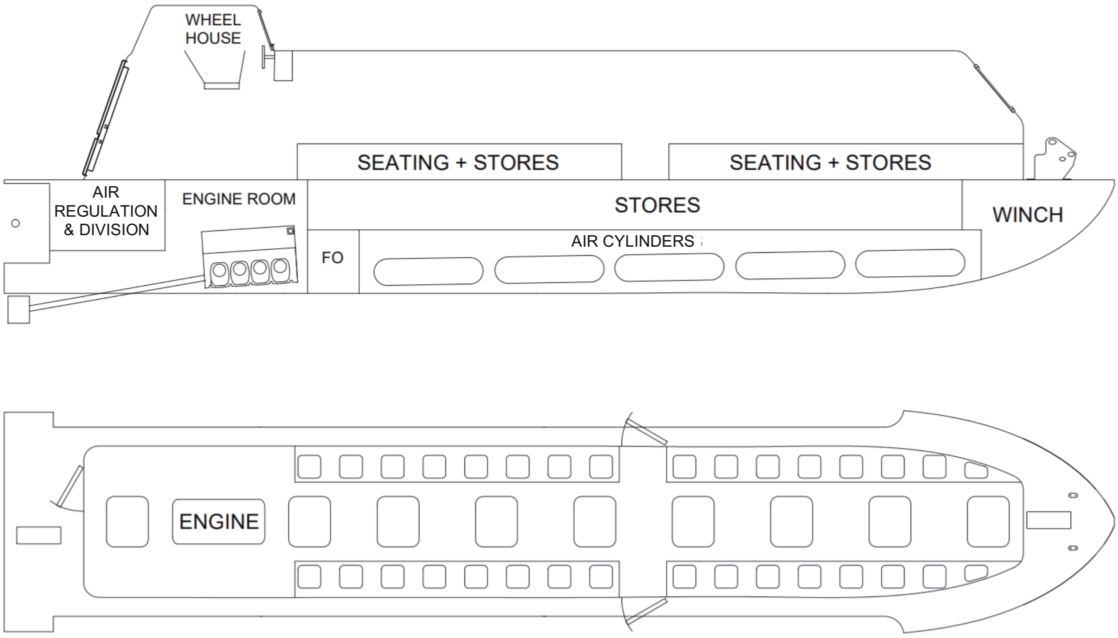

Figure 4 - General arrangement of the central hull

The general arrangement results in a maximum occupancy of 32 rescued persons in the main hull, 48 on the PEP and 210 on each of the SEPs. This is based on an area of $0.5m^2$ for each person on the expansion platforms and provides room to sit for all passengers.

3 Deployment

HiCEL can be configured for both rescue and abandonment operations. This flexibility extends to its initial launch procedure, with two options available to the MOSHIP.

3.1 Initial launch

HiCEL is either launched as the sole rescue vessel or used in tangent with a MOSHIP. With the former option the MOSHIP deploys HiCEL and its crew within range of the rescue datum. Once launched the MOSHIP continues with its intended operations whilst HiCEL rescues the evacuees. In the latter, the MOSHIP makes its way to the rescue datum whilst a separate crew board HiCEL and prepare for launch. Once in close proximity to the rescue datum, HiCEL is launched from the MOSHIPS davit and the CEP is deployed before recovery of the evacuees.

Figure 5 - Indicative concept of HiCEL, pre-deployment of CEP

3.2 *Deploying the CEP*

Each element of the CEP is deployed independently with the sequence determined by the rescue scenario. For large rescues of over 100 people both SEPs will be utilised. Each is contained within a buoyant housing known as the expansion shells which are stowed on the outside of the hull. Cut-outs are incorporated into the hull design to reduce the envelope of HiCEL when in its stowed position. The expansion shells are joined to the main hull using a reinforced universal joint arrangement, as shown in Figure 6. This removes any bending moments acting at the connection, due to the freedom of rotation. When required, the latches holding the expansion shells in place are released. The lifeboat is then propelled forward swinging the expansions shells into their deployed position.

The method described offers the simplest solution to deploy the SEPs. The hydrodynamic drag removes the need to provide an external force directly to the shells and further movement is prevented with the use of high strength mooring lines.

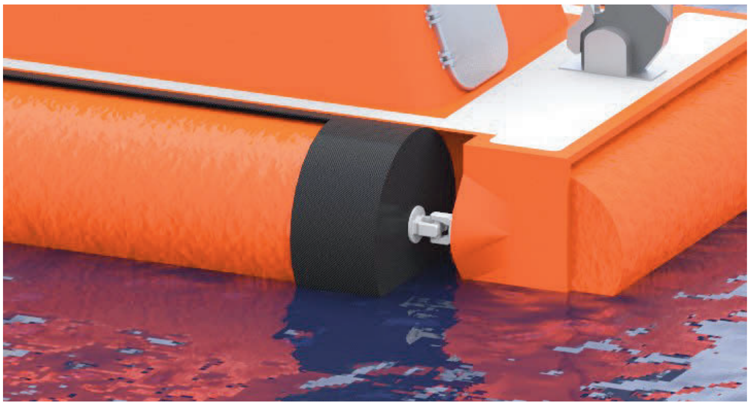

Figure 6 - Indicative concept of HiCEL connection between the expansion shell and the central hull

As contrast the PEP is housed internally at the stern of the central hull. The deflated platform is rolled around a drum and a manual crank and gearbox arrangement is operated by a crew member to unroll the platform. The mechanism is similar to a car winch. Unrolling is assisted by a sea anchor attached to the end of the PEP. The spacing constraints of the PEP housing limits the use of a motor to unroll the platform, however this option is used for the SEPs.

Once swung into position the SEPs are unrolled with the aid of electric motors and sea anchors. The motors drive a lightweight composite drum housed in both expansion shells at the aft end. In its pre-deployed state, the motor rotates the drum , this coupled with the pulling force of the sea anchors located on the ends of the platforms unrolls the SEPs. Electric, hydraulic and pneumatic powered options were all considered for the task, with a modified car winch identified as a suitable option. This was due to the low duty cycles required along and the ability to use the on-board 12v power supply.

3.3 *Inflating the Expansion Platforms*

Each platform is individually inflated in sections via high pressure compressed air cylinders located on the bottom deck. The total volume of drop stitched fabric to be inflated is detailed in Table 3:

Table 3 - Inflatable area required

Total area of inflatable required	234	m^2
Required inflation pressure	207 (30)	kPa (PSI)
Thickness of inflated drop stitch	0.15	m
Total air capacity	400	L

Figure 7 - Indicative concept of HiCEL, post expansion rear view

To minimise the storage requirements for the compressed air, a pressure of 350 bar is required. Each cylinder would be pre-charged and swapped out after use.

Table 4 - Cylinder requirements

Cylinder pressure	**345**	**kPa**
Cylinder capacity	88	L
Required capacity	400	L
No. of cylinders	5	-

The positioning of the compressed air system is shown in Figure 4. Each cylinder is connected to the manifold with flexible hosing. The manifold is operated via a control panel located at the helmsman position. The control panel houses release valves for the PEP along with both SEPs. Additional capacity is provided to allow topping up when required and redundancy if a release valve fails to operate. The high-pressure hosing runs along the bottom deck through water tight glands in the hull at the aft end where it connects to non-return valves within the CEP deck.

3.4 CEP Deck

The CEP was designed to accommodate a large influx of wet passengers. Unlike conventional life rafts and inflatable rescue platforms the HiCEL design does not prevent water ingress from occurring. To avoid the accumulation of water within the SEP from both green waves and the evacuees boarding the platforms, drainage valves were added along the edges of the SEP deck. Each platform provides a minimum freeboard of 750mm with the walls made up of four buoyancy tubes. The high freeboard reduces the risk that a passenger will enter the water during high sea states.

Each EP is compartmentalised, using non-return valves to connect neighbouring compartments. This arrangement ensures the platforms retain buoyancy even if one compartment deflates. Each SEP contains 6 compartments running longitudinally, with the inner compartment inflating first until all compartments are filled.

3.5 SEP Canopy

An open canopy has been located at the forward end of both the SEPs as shown in Figure 7. This arrangement provides a weather proof shelter with protection from sun exposure. The canopied area is only accessible from inside the SEP allowing for control of passengers. Additionally, in accordance with SOLAS regulations, the canopy is self-supported, using inflatable arches to provide rigidity to the canopy.

4 Recovery

4.1 Embarkation

HiCEL's larger recovery area for evacuees allows multiple evacuees to be rescued simultaneously. Unlike the traditional rescue boat and MOSHIP combination, HiCEL does not require repeated launch and recovery cycles for rescuing large numbers of evacuees. This coupled with the large recovery area has the potential to reduce the rescue time significantly when compared to traditional rescue methods.

4.1.1 Central Hull

The central hull utilises similar embarkation methods to conventional lifeboat or rescue boats. There are embarkation ladders situated on both portside and starboard of the main hull. Access points are located at both sides with a main access hatch located at the stern of the lifeboat. The lower freeboard at the stern allows for injured people to be hoisted onto the lifeboat.

4.1.2 PEP

Embarkation from this platform is achieved via the lowered platform situated at the aft end. A recess in the wall is provided to allow injured evacuees to be recovered onto the PEP with minimal effort. Anchor points are situated beside the recessed wall to allow trained personnel to aid the recovery of evacuees from the water whilst ensuring they are safely held in place.

4.1.3 SEP

Embarkation onto the SEPs is similar to the PEPs, with an outer platform running transversely along the aft end of both platforms. Embarkation is aided with the use of nets and embarkation ladders attached to the platform. The rescue crew can control the flow of people onto the SEPs and ensure that recovery is completed from the outer platforms. Lifelines run along the outer walls of the SEP providing support for evacuees who can make their way to the recovery area. The crew can then gesture evacuees onto areas of the platform to ensure even distribution.

4.2 Disembarkation

The design of HiCEL offers multiple disembarkation methods. For littoral areas it may be preferable for HiCEL to make its own way back to port. Where there are adverse weather conditions however, it is likely that disembarking the passengers onto a larger vessel will be the preferred option.

For MOSHIP disembarkation HiCEL is positioned alongside the vessel. For smaller rescue operations not needing the use of the CEP, HiCEL and its passengers can be recovered directly using the ship's davit or a suitable crane. For scenarios where the CEP has been deployed, embarkation ladders, scrambling nets or a rescue basket can be used. It is clear that HiCEL and the larger MOSHIP will be affected differently by sea states and wind conditions. As such manoeuvring HiCEL close to the vessel will be challenging. Care must be taken to ensure the MOSHIP does not collide with HiCEL and that they stay within range of disembarkation.

4.3 Stowage of CEP after use

Once disembarkation of HiCEL has been achieved it must be stowed for future use. The added complexity of HiCEL inevitably makes this process more laborious. Developing a reusable solution however could provide significant cost benefits. The proposed repacking process attempts to limit the effort and complexity of the task. To deflate the expansion platforms weights stored onboard must first be attached to the aft end of the platforms. The valves are released, to allow the gas to escape, with the weights pulling the platforms under water and forcing the gas out. The motors in the expansion shells can then be used to roll the drop stitch back into the expansion shells. The shells can then be pulled back into their original position, alongside the central hull, by winches holding the restraining cables in place.

5 Resistance and Propulsion

Clearly when the PEP and SEPs are deployed the hydrodynamic drag from seawater acting on the platforms will be significant. Initial hand calculations give indicative forces on HiCEL up to a maximum speed of 6kts. The following assumptions were made to simplify the calculations:

1. Frictional resistance provides up to 85% of resistance for low speed vessels and is estimated (IMO, 2009)
2. Residual resistances (wave and eddy) (typically up to 15% for slow moving vessels) are not estimated
3. Air resistance, due to the large frontal surface area of the platform is estimated

The effective power was estimated for the main hull and the CEP. An additional 15% margin was added to account for residual resistances (Molland, Turnock, & Hudson, 2011). Finally, a 30% power margin was used to account for adverse sea states (sea margin) as well as fouling (Molland, Turnock, & Hudson, 2011). This provides an estimate from which the required power could be determined. An engine size of 60KW was deemed as the minimum requirement to propel the unloaded and pre-deployed HiCEL at the required speed of 6kts. For a full complement with the CEP fully deployed, SOLAS regulations specify a speed of 2 kts towing a 25-person life raft. At this speed the fully deployed solution requires a minimum engine power of 30.5KW.

Auxiliary power requirements for unrolling the SEPS were also estimated. A simple torque calculation was completed with a rpm of 30. This would allow the SEP to be rolled out in a short period of time. An indicative power requirement of 4.5KW was determined.

6 Structures

Forces acting on the lifeboat and the expansion shells are also an important consideration. To ensure that they had sufficient reserves of strength hand calculations were completed to provide indicative forces. One of the largest risks for the design was the strength of the expansion shells, and the connections to the central hull. To address this the following free body diagram was made of the expansion shell, and the connections to the central hull, where label A represents the connection to the hull, B the end of the expansion shell connected via a mooring line to the hull, and W the load applied from the platform.

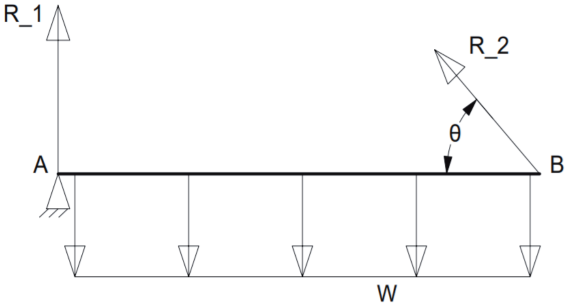

Figure 8 - FBD of the expansion shell

The driving forces in this diagram have been taken from the resistance and propulsion section of this paper, assuming a forward speed of 2 knots, and fully loaded.

$$\theta = 45° \tag{1}$$
$$w = 8.2kN\ (taken\ from\ the\ R + P\ calculations) \tag{2}$$
$$R_1 = 4.1kN \tag{3}$$
$$R_2 = 5.8kN \tag{4}$$

This gives a maximum bending moment at the centre of the beam of 10.25kNm. Assuming the shaft along the expansion shell to have an external diameter of 150mm, internal diameter of 134mm, and be made from extruded aluminium with an elastic modulus of 70GPa. The deflection of the shaft under the load shown in Figure 8 was calculated to be 60mm at the centre of the shaft.

The unique nature of this application for drop stitched fabric warranted the examination of the forces acting on it whilst in use. This would ensure that it would not buckle (or wrinkle) under the loads it would be subjected to. The stiffness of drop stitched material is comparable with that of a composite sandwich panel (Cavallaro, Hart, & Sadegh, 2013).

One interesting feature of any inflatable structure is the propagation of wrinkles, which is a phenomenon that occurs during bending of a panel, when the tension in one skin reduces to zero (Cavallaro, Hart, & Sadegh, 2013). Wrinkle propagation is elastic in nature and there are no lasting effects on the strength of the drop stitched fabric after use.

The key factors in the strength of drop stitch is the materials used in the wall and the inflation pressure. Whilst the design inflation pressure is known, there are a range of possible materials which could be used, and the scope of this paper has not allowed for an in-depth discussion of the pros and cons of different materials, and as such no particular skin material has been selected. Because of this the following calculations were completed to ensure the feasibility of drop stitch.

$$Internal\ pressure\ of\ drop\ stitch = P = 30psi = 2.07 * 10^5 Pa \tag{5}$$
$$Mass\ of\ each\ person =\ M_P = 75kg \tag{6}$$
$$Acceleration\ due\ to\ gravity = 9.81m/s^2 \tag{7}$$
$$Force\ from\ each\ person = F_P = M_P * g = 762N \tag{8}$$
$$Minimum\ area\ a\ person\ can\ act\ over\ before\ wrinkling = \frac{F_P}{P} = 3.68 * 10^{-3}m^2 \approx 6cm * 6cm \tag{9}$$

This conservative estimate (Equation 9) shows that an average person would have to apply their mass over an area smaller than 6 square centimetres before there would be any wrinkles forming.

Another simple static analysis of loads on the lines connecting the SEPs to the main hull was completed. From this an indicative tensile force of up to 5.2KN was determined for the mooring line. Whilst dynamic loads during rough seas are likely to be higher Commercial Off-The-Shelf (COTS) mooring lines can provide the required strength characteristics for this purpose.

7 Stability

The stability of HiCEL also requires consideration due to the different operational states. Figure 2 shows the three states pre-CEP deployment, CEP deployed, and the transitional state between the two. The pre-deployment state (Figure 2A) is the worst case due to the cut outs in the central hull for the expansion shells. This causes a reduction in the waterline beam, and hence a reduction in the righting lever of the central hull thereby decreasing the stability compared to a standard lifeboat. In the other two states however this stability reduction will be offset by the effect of the expansion platforms acting as stabilisers and preventing roll motions.

8 Costing

A rough order of magnitude (ROM) cost of £214k for the design has been estimated using COTS equipment and public data. The most significant cost involved can be attributed to the CEP made up of drop stitched fabric, where the estimation was based upon cost per area. Using polyethylene fabric, a commonly used drop stitch material, gives a cost of £95 per m^2 for a thickness of 150mm (Henshaw, 2018). An additional margin of 50% was added to the total cost to account for labour costs and other unknowns.

Table 5 - HiCEL ROM Cost

Main hull	**£60,000**
Auxiliary motor & mods	**£810**
Aluminium tubing drum	**£2,000**
Carbon fibre shell	**£2,754**
Heavy duty batteries	**£240**
High pressure gas cylinders	**£2,100**
High pressure hosing and auxiliary equipment	**£25,150**
Expansion platforms	**£30,000**
Auxiliary equipment	**£20,000**
Total cost	**£143,054**
Total cost with a 50% margin	**£214,581**

In comparison market research has indicated a 50-person conventional lifeboat can cost up to £60K and 150-person costing over £100k. Evidently HiCEL is costlier as a survival craft than a conventional lifeboat. HiCEL however also has the capability of being a first responder during a SAR operation. As such it can reduce the time a MOSHIP has to be involved in the rescue or replace its need to be diverted altogether, thereby reducing the financial burden.

9 Retrofitting

An alternative solution to manufacturing a bespoke solution is retrofitting the CEP to existing lifeboats. A comparable lifeboat design such as the Maxima 120, manufactured by NORSAFE could be utilised for this solution. Using a COTS lifeboat would result in significant initial savings on the cost to develop and manufacture a bespoke solution. The Maxima 120 has a comparable operating envelope with a length and beam of 12.02m x 3.96m respectively.

Whilst modifications would need to be made to the COTS lifeboat it is likely that the cost of these would be less than the costs involved in designing and manufacturing a new hull. It would also decrease the manufacturing time, making them available sooner. If the capacity of the main hull was reduced it would allow additional space for the extra LSA's required such as lifejackets and stretchers. There would also need to be some consideration to the structural strength of the lifeboat, and any modifications made as necessary.

10 Air deployment

This alternative deployment method was explored for the paper. Air deployment, commonly known as an airdrop, could provide a solution to reach more isolated areas. Airdrops have been used recently to deliver humanitarian supplies to conflict zones such as Syria (Abdalla, 2017). The method has also been used within the military for vehicles that are larger and heavier than HiCEL. Large cargo planes such as the A400M or the C130 would be required due to the large payload and dimensions of HiCEL. With this method multiple HiCELs could be strategically positioned at airports globally, and when required suitable aircraft could be chartered to fly HiCEL to the required area and airdropped. Low velocity airdrops would be required to limit the shock loading on HiCEL and prevent damage to the hull. This method would require significant investigation into the operating costs of aircraft chartership and to determine if this is a viable alternative.

11 Conclusions

In summary a design to combat the modern SAR challenge has been presented, with particular interest paid to the innovative material selection of drop stitch fabric. With drop stitched platforms HiCEL can expand to radically increase its complement and save lives without compromising on its stowage space. Evacuees can be recovered quickly from multiple platforms thereby reducing the rescue time. HiCEL also has the flexibility to be used for both survival and rescue purposes and could replace the need for another vessel to be diverted for rescue altogether.

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