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(71) Applicant: **Dark Ocean Limited
Meavy, Devon PL20 6PL (GB)**

(72) Inventor: **RAMSAY, John Alister
Meavy, PL20 6PL (GB)**

(74) Representative: **Muttock, Henry Paul Jones
Muttock IP Ltd
Office 13460
182-184 High Street North
London E6 2JA (GB)**

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(54) **PRESSURE HULL FOR HUMAN OCCUPANCY FOR MANNED SUBMERSIBLES**

(57) The invention provides a pressure hull (1) for
human occupancy for manned submersible vessels,
wherein the hull (1) is formed from acrylic, characterised
in that the hull has a circular, or near-circular, cross-

section across a major axis (2) and has an elongated,
non-uniform profile along the major axis (2). The inven-
tion further provides a manned submersible including a
pressure hull (1).

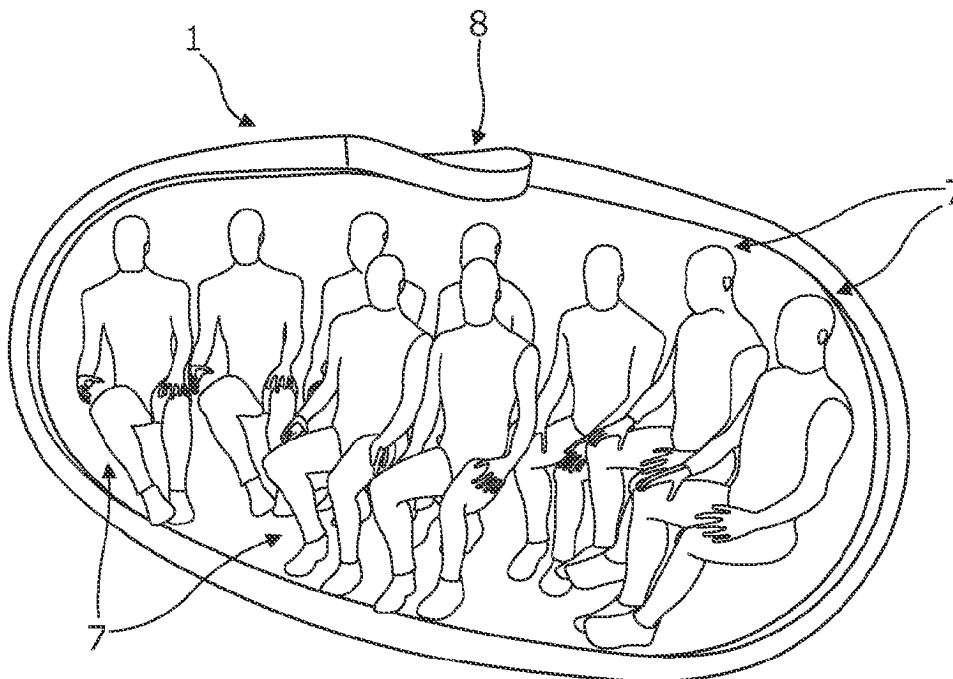


Fig. 2

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Description

FIELD OF THE INVENTION

[0001] The invention relates to manned-submersible vessel pressure hulls for human occupancy. Such pressure hulls are also referred to as pressure vessels for human occupancy (PVHO).

BACKGROUND OF THE INVENTION

[0002] A pressure hull, or pressure vessel, for human occupancy is the hull in which a pilot and any passengers sit in a manned submersible for underwater use. These hulls are commonly made of steels, titanium and other metals. Alternatively, they may be made partially or wholly of acrylic.

[0003] A PVHO is defined as a vessel under internal or external pressure that is occupied by a human. Any 'one atmosphere' passenger-carrying submersible requires a PVHO for the passengers.

[0004] Spherical acrylic hulls were developed in the 1960's, with further development through the 1970's and 1980's, and the rules for their manufacture are set out in the American Society of Mechanical Engineers' Safety Standard for Pressure Vessels for Human Occupancy (<https://www.asme.org/codes-standards/find-codes-standards/pvho-1-safety-standard-pressure-vessels-human-occupancy>). A number of different submersibles with spherical hulls are known for shallow and medium depth diving but these have limited occupancy as their size is limited by various constraints such as weight, ease of manufacture and ability to use them on ships, such as yachts, and loading gantries. As such, the maximum practical diameter of spherical pressure hulls is about 2.5m, which limits the comfortable accommodation of occupants to about 6. While some spheres have been proposed with higher occupancy possibilities, these are crowded and have limited visibility for some of the occupants.

[0005] There are many situations in shallow and medium depth diving (for example, up to 500m or greater), where it is advantageous to have several people carried in a submersible, but it is also desirable for these occupants to be comfortable and to have clear and unobstructed views out of the vessel. One option has been to develop long, cylindrical hulls. These are made from sections of acrylic fastened together with metal bands. Such cylindrical hulls have limited seating arrangements, are not very manoeuvrable and are limited to relatively shallow dives.

[0006] Another suggestion for increasing the capacity of pressure hulls for human occupancy has been to join combinations of spheres, hemispheres and cylinders, with the sections being joined by metal bands. These still have limited visibility for the occupants, are complicated to manufacture and add components, complexity and cost to the submersible. Additionally, the need to use

metal bands to join the sections adds further restrictions on the viewing angles for occupants.

[0007] CN 11101768A discloses a semi-submersible sight-seeing boat with a transparent cabin body and a connection and installation frame to fix the cabin body on a floating body.

SUMMARY OF THE INVENTION

[0008] The invention provides a manned-submersible vessel pressure hull for human occupancy for, wherein the hull is formed from acrylic, characterised in that the hull has a circular, or near-circular, cross-section across a major axis and has an elongated, non-uniform profile along the major axis.

[0009] The invention further provides a manned-submersible vessel comprising ballast tanks, propulsion means and a pressure hull in accordance with the invention. The pressure hull may be arranged within the manned submersible vessel such that the major axis of the hull extends laterally across the vessel, to provide a wide forward view for occupants of the vessel. Alternatively, the pressure hull may be arranged within the manned submersible vessel such that the major axis of the hull extends longitudinally along the vessel to provide lateral views for the occupants of the vessel. Such submersible vessels are suitable for use at shallow and medium depths, and will even be suitable for some deeper uses, if desired.

[0010] In accordance with the invention, the cross-section of the hull through the major axis is circular or near-circular, such that the stresses resulting from external pressure generate a positive compressive stress in the acrylic. As such, the cross-section may be slightly oval in shape or have local deviations from circular form. Such deviations may include deviations on the inside face of the hull, such as localized "flattening" of the acrylic to reduce distortion for viewing out of the hull. Additional deviations from circular cross-sections may also include localized thickening of the acrylic in proximity to an access hatch in order to reduce contact stresses in the acrylic-hatch interface.

[0011] Additional deviations from a circular cross-section may be used to improve ergonomics and passenger space within the hull compartment. Where the cross-section across the major axis is referred to as "circular" in this specification, this should be understood to encompass references to near-circular, as discussed.

[0012] In accordance with embodiments of the invention, the diameter of the circular cross-section of the pressure hull across the major axis is greater at the centre of the hull profile than at the ends. The pressure hull has an elongated non-uniform profile extending along the length of the major axis. In one embodiment, the invention provides an acrylic pressure hull that is spheroidal in shape. In one example, the pressure hull has an elliptical cross-section in the longitudinal direction. In an alternative embodiment, the pressure hull has a longitudinal

profile that has a relatively large radius over the central portion, with the radius of the profile decreasing towards the ends of the pressure hull. In another embodiment, the central portion of the pressure hull has an elongated, non-uniform profile along the major axis and the ends of the hull are truncated and finished with end plates of another material such as metal.

[0013] Advantageously the height of the pressure hull in a central portion of the hull is of a height that is comfortable for occupants to move around the hull and to sit in comfort.

[0014] The elongated profile of the hull along the major axis enables the occupants to be positioned within the hull such that each occupant has a clear, unobstructed line-of-sight forwards out of the pressure hull. In an alternative arrangement, the major axis of the hull can be aligned within the submersible vessel such that each occupant has a clear, unobstructed line-of-sight laterally from the pressure hull.

[0015] The pressure hull of the invention can accommodate several occupants without having to increase the height of the hull or form the hull from multiple sections. The pressure hull of the invention can be configured with suitable arrangements for any of one or several occupants. The pressure hull of the invention is particularly advantageous for increasing the capacity for occupants without significantly increasing the displacement of the hull. However, lower capacity arrangements may also be advantageous if an ultra-low displacement submersible is desirable. Preferably the pressure hull of the invention is arranged to accommodate four or more occupants. The pressure hull of the invention can comfortably accommodate 7, 9 or even more occupants in seating arrangements that allows each occupant to have a clear forward and/or lateral line of sight without having to increase the height of the pressure hull. The pressure hull of the invention can accommodate more people than has previously been possible in comfort in a single piece acrylic hull, whilst still having a compact footprint and low displacement and without having to increase the height of the hull. This is particularly advantageous for use on yachts, where the submersible will need to fit into limited storage space, or in dock areas where there may be crane hooks with restricted height. The low displacement of the hull keeps the weight of the hull to a minimum for the required occupancy, which is critical for manned submersibles.

[0016] Preferably the pressure hull is made as a single piece. Alternatively, the pressure hull is made from segments of acrylic that are bonded together. The acrylic hull or hull segments are advantageously made by slush casting or thermoforming, which are known methods of forming acrylic shapes. Segments are bonded using known acrylic bonding techniques. The pressure hull may be formed as a complete spheroidal or similar profile or may be formed with truncated ends.

[0017] Advantageously an access hatch is arranged on an axis that intersects the central axis. Advanta-

geously the access hatch is arranged on the top surface of the pressure hull for ease of entry and exit of the pressure hull when the submersible vessel is on the surface of the water.

[0018] Advantageously, the seating positions for occupants can be arranged in different formations within the pressure hull. This enables a submersible vessel including a pressure hull of the invention to be used for a variety of different purposes, depending on the requirements of the user.

[0019] To have a better understanding of the invention reference is made to the following non-limiting description of the invention and embodiments thereof in conjunction with the accompanying drawings. The figures are not necessarily to scale, and certain features and certain views of the figures may be shown exaggerated in scale or in schematic form in the interests of clarity and conciseness.

BRIEF DESCRIPTION OF THE DRAWINGS

[0020]

Figures 1A and 1B show length-wise cross-sectional views of different non-limiting embodiments of the invention;

Figure 2 shows a cut-away perspective view of one embodiment of the invention, showing a possible seating arrangement for occupants;

Figure 3 shows a front, perspective view of an alternative embodiment of the invention; and

Figures 4A and 4B shows perspective views of a manned submersible vessel in accordance with the invention, including a pressure hull and showing examples of alternative seating arrangement for occupants.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0021] Figures 1A and 1B show two non-limiting alternative arrangements of a pressure hull in accordance with the invention. As shown in Figures 1A and 1B, the hull 1 has a major axis 2 that extends along the hull 1 and has an elongated, non-uniform profile 3. The cross-section of the hull 1 across the major axis is circular at each point along the major axis 2.

[0022] The profile 3 is curved and the height of the hull is increased at the centre 4 compared to the ends 5a and 5b.

[0023] Such a shape of hull has many advantages over prior art hulls and has surprisingly been found to comply with the required strength and stress factors for submersible use, despite not comprising the standard geometries that are expected for use in pressure hulls in current submersibles.

[0024] Pressure hulls having a shape in accordance with the invention are extremely efficient from a displace-

ment perspective and allow a greater number of occupants in a pressure vessel having a more compact footprint than has previously been possible. A particular advantage of the pressure hull of the invention is that the hull has a low overall height without requiring the top and/or bottom of the hull to be cut off and it also has a low displacement, and hence weight, which is a critical factor for manned submersible vessels.

[0025] Prior art spherical hulls can be designed by code calculations from, for example, the Mechanical Engineers' Safety Standard for Pressure Vessels for Human Occupancy, referred to above. In contrast, a pressure hull with a non-uniform profile in accordance with the invention must be designed using Finite Element Analysis, which has not previously been needed for spherical acrylic hulls.

[0026] Figure 1A shows a spheroidal hull, which is particularly advantageous in relation to the displacement for any particular number of occupants. Figure 1B shows a hull having a longitudinal profile that has a relatively large radius over the central portion 6, with the radius of the profile decreasing towards the ends 5a, 5b of the pressure hull. This arrangement has an advantage in that the usable headroom can be increased along a greater portion of the hull without having to increase the maximum headroom.

[0027] Figure 2 shows a possible arrangement of seating for nine occupants 7. The occupants 7 can be comfortably seated within the pressure hull 1 with each occupant 7 having a clear and unobstructed forward line-of-sight. Optionally, the hull 1 may include an access hatch 8 in the top surface of the hull 1.

[0028] Figure 3 shows an alternative hull arrangement 11. The hull 11 has an elongated non-uniform profile along the major axis 12 and a circular cross-section 13 across the major axis 12. The ends of the hull 15a, 15b are truncated and are sealed with metal plates forming end-caps 16a, 16b. The end-caps 16a, 16b may be used to provide mounting points for the pressure hull 1 and/or to reduce displacement and overall length while maintaining a usable diameter within the hull 1 interior.

[0029] The seating arrangements for occupants 7 shown in Figures 2 and 3 can be changed to accommodate different numbers of occupants in various different seating arrangements. Each occupant 7 has an unobstructed line-of-sight, making the hull effective for submersibles to carry several occupants to view underwater sites in a way that is significantly more comfortable and effective than prior art submersibles have been able to achieve.

[0030] Figures 4A and 4B show an example of a manned submersible 40 including a pressure hull 1 arranged in a lateral position. The ballast tanks 41, propulsion systems 42 and superstructure 43 of the submersible 40 are arranged to provide optimum viewing from the hull 1 and the seating 44 within the hull 1 is arranged to suit the desired purpose of the use of the submersible, such as viewing underwater wrecks, reefs, marine life,

etc, or for use for educational events or social events such as dining. Figure 4a shows seating 44 including tables 45 or similar. In an alternative arrangement shown in Figure 4B, the occupants may be seated in comfort to view forward out of the hull 1. In other alternative arrangements (not shown) the hull 1 may be arranged in a longitudinal position such that the occupants can view with an unobstructed line-of-sight out of the length of the hull 1, which then forms the sides of the vessel 40 from the occupants' point of view.

[0031] The optimal viewing arrangements can be configured to suit a variety of different dimensions of manned submersible, but a particular advantage is that the number of occupants that can be accommodated can be increased without increasing the overall height of the submersible. This is particularly useful when the submersible needs to fit into a given space such as a garage space on a yacht or underneath a crane hook with limited height.

[0032] Preferences and options for a given aspect, feature or parameter of the invention should, unless the context indicates otherwise, be regarded as having been disclosed in combination with any and all preferences and options of all other aspects, features and parameters of the invention.

[0033] While the embodiments described herein are intended as exemplary, it will be appreciated by those skilled in the art that the present invention is not limited to the embodiments illustrated. Those skilled in the art will envision many other possible variations and modifications by means of the skilled person's common knowledge without departing from the scope of the invention, however, such variations and modifications should fall into the scope of this invention.

CLAUSES

[0034]

1. A manned-submersible vessel pressure hull for human occupancy, wherein the hull is formed from acrylic, characterised in that the hull has a circular or near-circular cross-section across a major axis and has an elongated, non-uniform profile along the major axis.

2. The pressure hull according to clause 1, wherein the hull has seating positions for multiple occupants with forward and/or lateral line of sight out of the hull.

3. The pressure hull according to clause 2, wherein the number of possible occupants is at least four.

4. The pressure hull according to any one of the preceding clauses, wherein the hull is spheroidal in shape.

5. The pressure hull according to any one of the

preceding clauses, wherein the hull is formed as a single unit.

6. The pressure hull according to any one of the preceding clauses, wherein the hull has a central section formed as a single unit and has an end cap at each end of the central section.

7. The pressure hull according to clause 6, wherein the end caps are metal.

8. The pressure hull according to any one of the preceding clauses, wherein the hull has an access hatch positioned on the surface of the hull on an axis that intersects with the central axis.

9. The pressure hull according to clause 8, wherein the access hatch is positioned on the upper surface of the hull.

10. The pressure hull according to any one of the preceding clauses, wherein the hull is formed by slush casting or by thermoforming.

11. A manned-submersible vessel comprising:

a pressure hull according to any one of the preceding clauses; ballast tanks; and propulsion means.

12. A submersible vessel according to clause 11, wherein the pressure hull is arranged with the major axis transverse to the normal direction of motion of the vessel to provide occupants of the pressure hull a clear, forward line-of-sight.

13. A submersible vessel according to clause 11, wherein the pressure hull is arranged with the major axis along the normal direction of motion of the vessel to provide occupants of the pressure hull a clear, lateral line-of-sight.

Claims

1. A manned-submersible vessel pressure hull (1) for human occupancy, wherein the hull is formed from acrylic, wherein the pressure hull (1) is made as a single piece or made from segments of acrylic that are bonded together using known acrylic bonding techniques, **characterised in that** the hull (1) has a circular or near-circular cross-section across a major axis (2) and has an elongated, non-uniform profile along the major axis (2), wherein the pressure hull (1) has an elliptical cross-section in the longitudinal direction.

2. The pressure hull (1) according to claim 1, wherein the hull (1) has seating positions for multiple occupants (7) with forward and/or lateral line of sight out of the hull (1).

3. The pressure hull (1) according to claim 2, wherein the number of possible occupants (7) is at least four.

4. The pressure hull (1) according to any one of the preceding claims, wherein the hull (1) is formed as a single unit.

5. The pressure hull (1) according to any one of the preceding claims, wherein hull (1) has a central section (6) formed as a single unit and has an end cap (16a, 16b) at each end of the central section.

6. The pressure hull according to claim 6, wherein the end caps (16a, 16b) are metal.

7. The pressure hull (1) according to any one of the preceding claims, wherein the hull (1) has an access hatch (8) positioned on the surface of the hull (1) on an axis that intersects with the central axis.

8. The pressure hull according to claim 7, wherein the access hatch (8) is positioned on the upper surface of the hull (1).

9. The pressure hull (1) according to any one of the preceding claims, wherein the hull (1) is formed by slush casting or by thermoforming.

10. A manned-submersible vessel (40) comprising:

a pressure hull (1) according to any one of the preceding claims;
ballast tanks (41); and
propulsion means (42).

11. A submersible vessel according to claim 10, wherein the submersible vessel further comprises a superstructure (43).

12. A submersible vessel (40) according to claim 10, wherein the pressure hull (1) is arranged with the major axis (2) transverse to the normal direction of motion of the vessel (40) to provide occupants (7) of the pressure hull (1) a clear, forward line-of-sight.

13. A submersible vessel (40) according to claim 10, wherein the pressure hull (1) is arranged with the major axis (2) along the normal direction of motion of the vessel (40) to provide occupants (7) of the pressure hull (1) a clear, lateral line-of-sight.

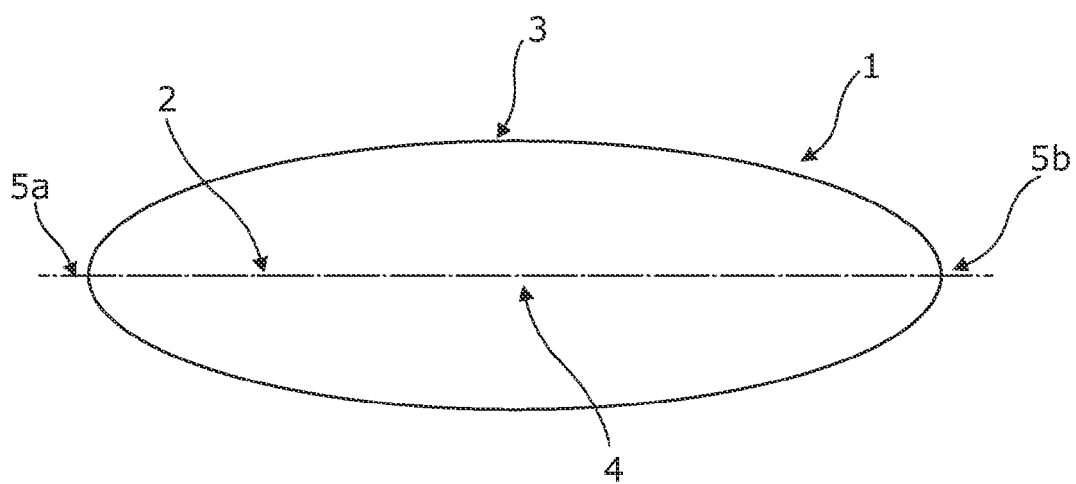


Fig. 1A

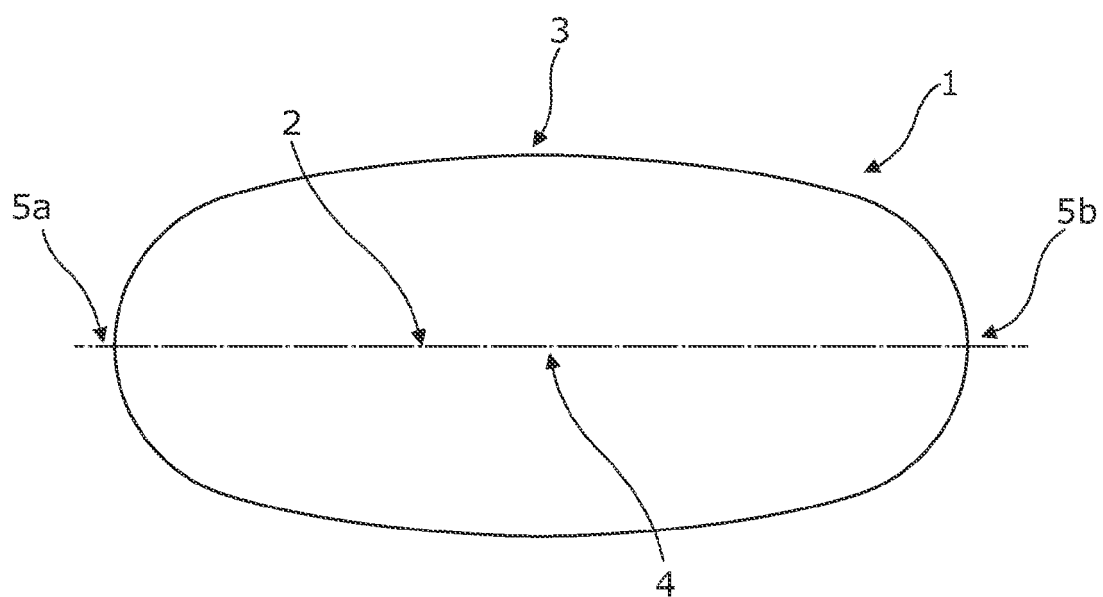


Fig. 1B

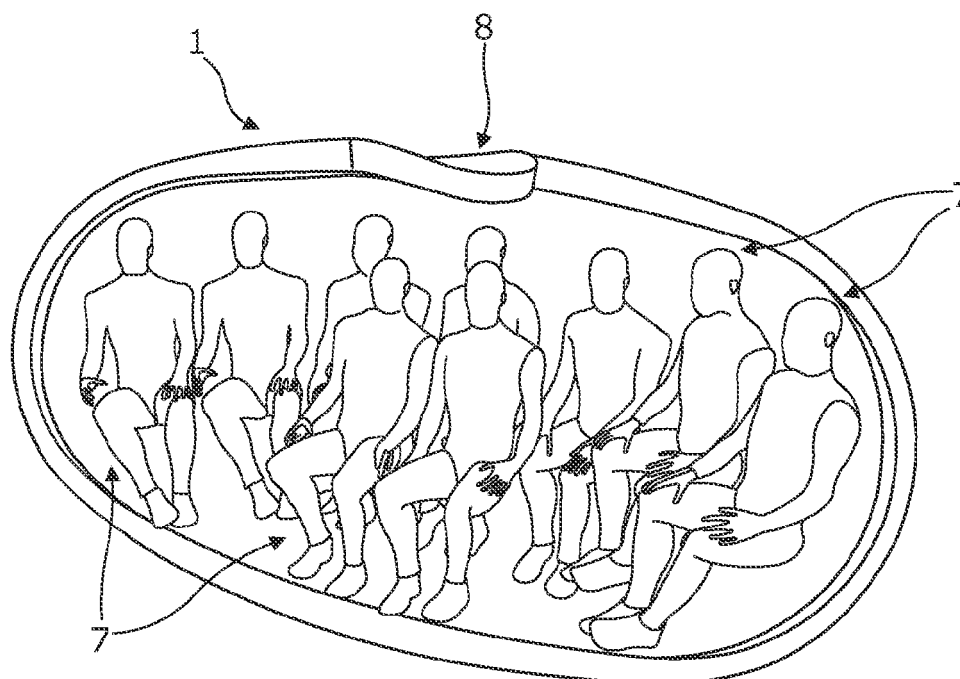


Fig. 2

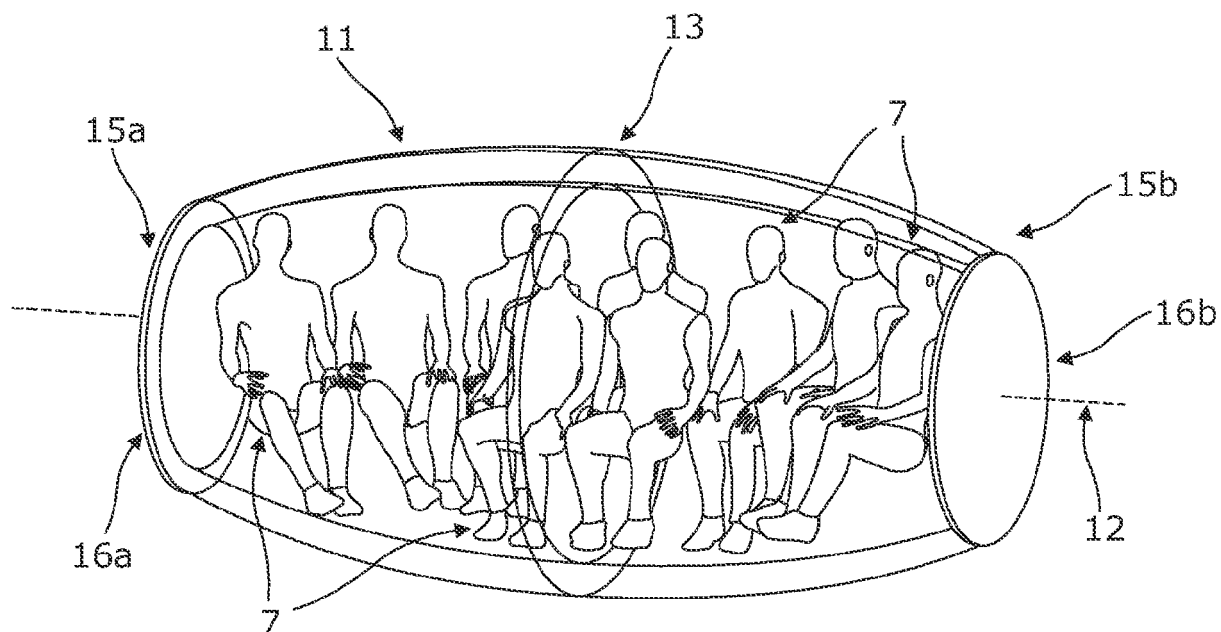
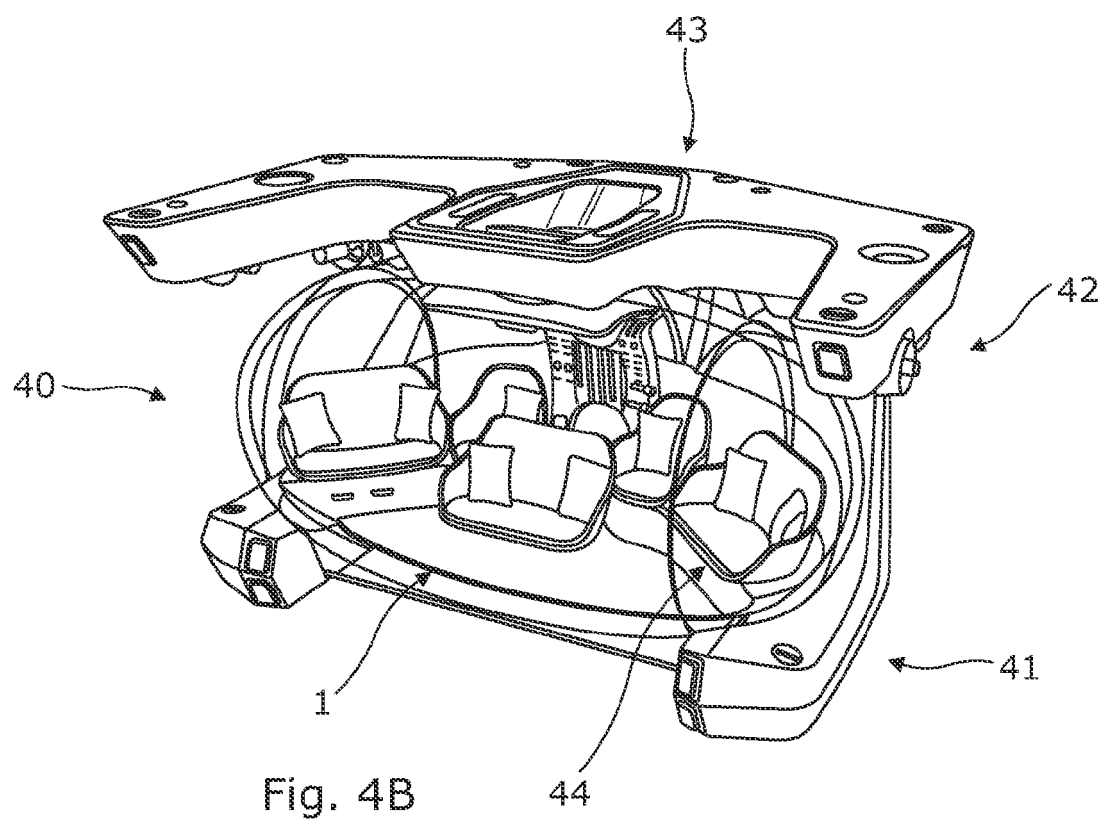
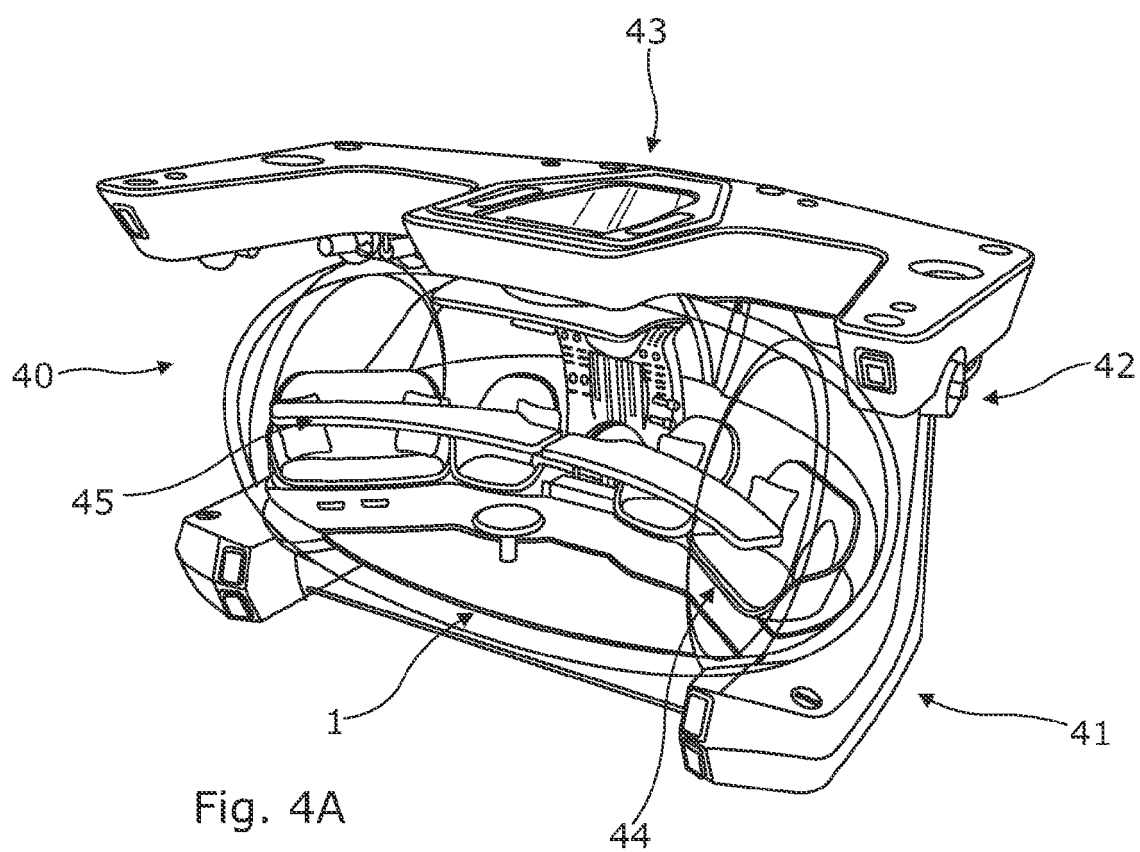


Fig. 3



REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- CN 11101768 A [0007]