A sixth aspect of the invention provides a propulsion system for a submersible vehicle, the propulsion system comprising two or more axi-symmetrical drive assemblies housed within a flexible substantially annular jacket.

A seventh aspect of the invention provides a method of operating a submersible vehicle having two or more axi-symmetrically mounted drive assemblies, the method comprising reciprocating the drive assemblies axi-symmetrically so as to propel the vehicle through a liquid.

An eighth aspect of the invention provides a submersible vehicle having an outer hull which defines a hull axis and appears substantially annular when viewed along the hull axis, the interior of the annulus defining a duct which is open at both ends so that when the vehicle is submerged in a liquid, the liquid floods the duct; and a twin thrust vector propulsion system comprising one or more pairs of propulsion devices, each pair comprising a first propulsion device pivotally mounted on a first side of the hull axis, and a second propulsion device pivotally mounted on a second side of the hull axis opposite to the first propulsion device.

Typically each propulsion device generates a thrust vector which can be varied independently of the other propulsion device by pivoting the device. Typically each device is mounted so that it can pivot about an axis at an angle (preferably 90°) to the hull axis. The propulsion devices may be, for example, rotating propellers or reciprocating fins. The propulsion devices may be inside the duct, or outside the duct but conformal with the outer hull.

A ninth aspect of the invention provides a submersible toy glider having an outer hull which defines a hull axis and appears substantially annular when viewed along the hull axis, the interior of the annulus defining a duct which is open at both ends so that when the toy glider is submerged in a liquid, the liquid floods the duct, wherein at least part of the outer hull is swept with respect to the hull axis.

Another aspect of the invention provides a method of operating a vehicle according to any aspect or embodiment of the invention, the method comprising: submerging the vehicle in a liquid whereby the liquid floods the duct, and rolling the vehicle about its hull axis.

The following comments apply to all aspects of the invention.

CLAIMS

1. A submersible vehicle having an outer hull which defines a hull axis and appears substantially annular when viewed along the hull axis, the interior of the annulus defining a duct which is open at both ends so that when the vehicle is submerged in a liquid, the liquid floods the duct, the vehicle further comprising means for rolling the vehicle about the duct.

2. A vehicle according to any preceding claim wherein the means for rolling the vehicle about the duct is positioned in the duct.

3. A vehicle according to any preceding claim wherein the means for rolling the vehicle about the duct comprises a propulsion system.

4. A vehicle according to claim 3 wherein the propulsion system has rotational symmetry about the hull axis.

5. A vehicle according to claim 3 or 4 wherein the propulsion system comprises one or more pairs of propulsion devices, each pair comprising a first device pivotally mounted on a first side of the hull axis, and a second device pivotally mounted on a second side of the hull axis opposite to the first device.

6. A vehicle according to any preceding claim wherein the means for rolling the vehicle about the duct comprises one or more control surfaces.

7. A vehicle according to claim 6 wherein the means for rolling vehicle about the duct comprises one or more pairs of control surfaces, each comprising a first control surface on a first side of the hull axis, and a second control surface on a second side of the hull axis opposite to the first control surface.

8. A vehicle according to claim 6 or 7 wherein the or each control surface comprises a fin.

9. A vehicle according to any preceding claim wherein the means for rolling the vehicle about the duct comprises an inertial control system comprising one or more masses, each of which can be accelerated so as to impart an equal and opposite acceleration to the vehicle.

10. A vehicle according to any preceding claim further comprising a buoyancy control system.

11. A submersible vehicle having an outer hull which defines a hull axis and appears substantially annular when viewed along the hull axis, the interior of the annulus defining a duct which is open at both ends so that when the vehicle is submerged in a liquid, the liquid floods the duct, the vehicle further comprising a buoyancy control system.

12. A vehicle according to claim 10 or 11 wherein the buoyancy control system has rotational symmetry about the hull axis.

13. A vehicle according to any preceding claim wherein at least part of the outer hull is swept with respect to the hull axis.

14. A submersible vehicle having an outer hull which defines a hull axis and appears substantially annular when viewed along the hull axis, the interior of the annulus defining a duct which is open at both ends so that when the vehicle is submerged in a liquid, the liquid floods the duct, wherein at least part of the outer hull is swept with respect to the hull axis.

15. A vehicle according to any preceding claim wherein the hull has a projected area S, and an maximum outer diameter B normal to the hull axis, and wherein the ratio $B^2/S$ is less than 1.

16. A vehicle according to any preceding claim wherein the hull has a projected area S, and a maximum outer diameter B normal to the hull axis, and wherein the ratio $B^2/S$ is greater than 0.5.

17. A submersible vehicle having an outer hull which defines a hull axis and appears substantially annular when viewed along the hull axis, the interior of the annulus defining a duct which is open at both ends so that when the vehicle is submerged in a liquid, the liquid floods the duct, wherein the hull has a projected area S, and a maximum outer diameter B normal to the hull axis, and wherein the ratio $B^2/S$ is greater than 0.5.

18. A vehicle according to any preceding claim wherein the interior of the annulus is shaped so as to appear at least partly curved when viewed in a cross section taken along the hull axis.

19. A vehicle according to any preceding claim wherein the interior and exterior of the annulus are shaped so as to provide a hydrofoil profile when viewed in a cross section taken along the hull axis.

20. A vehicle according to claim 19 wherein the hydrofoil profile has a relatively wide section at an intermediate position along the hull axis, and relatively narrow sections fore and aft of the intermediate position.

21. A vehicle according to any preceding claim further comprising one or more pressure vessels housed inside the outer hull.

22. A vehicle according to claim 21 wherein at least one of the pressure vessels appears substantially annular when viewed along the hull axis.

23. A vehicle according to claim 21 or 22 comprising two or more pressure vessels spaced apart along the hull axis.

24. A vehicle according to claim 21, 22 or 23 wherein an interior space between the pressure vessel(s) and the outer hull is flooded when in use.

25. A vehicle according to any preceding claim further comprising an energy source housed at least partially inside the outer hull.

26. A vehicle according to any preceding claim further comprising one or more sensors.

27. A vehicle according to claim 26 wherein at least one of the sensors comprises a proximity sensor.

28. A vehicle according to claim 27 further comprising a propulsion system; and a feedback mechanism for adjusting the propulsion system in response to a signal from the proximity sensor.

29. A vehicle according to any preceding claim wherein the vehicle has a center of gravity located in the duct and a center of buoyancy located in the duct.

30. A vehicle according to any preceding claim wherein the vehicle has a center of gravity located approximately on the hull axis and a center of buoyancy located approximately on the hull axis.

31. A submersible vehicle having an outer hull which defines a hull axis and appears substantially annular when viewed along the hull axis, the interior of the annulus

defining a duct which is open at both ends so that when the vehicle is submerged in a liquid, the liquid floods the duct; and a twin thrust vector propulsion system comprising one or more pairs of propulsion devices, each pair comprising a first propulsion device pivotally mounted on a first side of the hull axis, and a second propulsion device pivotally mounted on a second side of the hull axis opposite to the first propulsion device.

32. A submersible vehicle having an outer hull which defines a hull axis and appears substantially annular when viewed along the hull axis, the interior of the annulus defining a duct which is open at both ends so that when the vehicle is submerged in a liquid, the liquid floods the duct.

33. A method of operating a vehicle according to any preceding claim, the method comprising: submerging the vehicle in a liquid whereby the liquid floods the duct, and rolling the vehicle about its hull axis through a plurality of revolutions.

34. A method according to claim 33 further comprising maintaining the vehicle with substantially no translational movement whilst rolling the vehicle about its axis.

35. A method according to claim 33 further comprising inclining the vehicle at an angle to a current in the liquid whilst rolling the vehicle about its axis, thereby generating magnus forces.

36. A method according to claim 33 further comprising pulsing on a propulsion system over a limited arc of revolution of the vehicle.

37. A method according to claim 33 wherein the vehicle comprises a sensor, and the method further comprises translating the vehicle whilst rolling the vehicle about its axis, and acquiring sensor data from the sensor more than once per revolution.

38. A method according to claim 37 further comprising processing the sensor data from successive revolutions to achieve synthetic extension of the sensor's aperture in two dimensions.

39. A method according to claim 33 further comprising sensing the proximity of the vehicle to an external object and controlling the position of the vehicle in response to the sensed proximity.

40. A method according to claim 33 further comprising laying a cable from the vehicle.

41. The use of a vehicle according to any of claims 1 to 32 comprising submerging the vehicle in a liquid-filled pipe for inspection, repair or other purposes.

42. A method of docking a vehicle according to any of claims 1 to 32, the method comprising inserting the vehicle into a substantially cylindrical dock.

43. A method of docking a vehicle according to any of claims 1 to 32, the method comprising inserting a dock projection into the duct.

44. A method of deploying a vehicle according to any of claims 1 to 32, the method comprising deploying the vehicle from a substantially cylindrical dock.

45. A method of deploying a vehicle according to any of claims 1 to 32, the method comprising deploying the vehicle from a dock projection received in the duct.

46. A propulsion system for a submersible vehicle, the propulsion system comprising two or more axi-symmetrical drive assemblies housed within a flexible substantially annular jacket.

47. A method of operating a submersible vehicle having two or more axi-symmetrically mounted drive assemblies, the method comprising reciprocating the drive assemblies axi-symmetrically so as to propel the vehicle through a liquid.

48. A method according to claim 47 wherein the drive assemblies are fins.

49. A method according to claim 47 wherein the drive assemblies are housed within a flexible substantially annular jacket.

50. A submersible toy glider having an outer hull which defines a hull axis and appears substantially annular when viewed along the hull axis, the interior of the annulus defining a duct which is open at both ends so that when the toy glider is submerged in a liquid, the liquid floods the duct.

51. A toy glider according to claim 50, wherein the hull has a projected area S, and a maximum outer diameter B normal to the hull axis, and wherein the ratio $B^2/S$ is greater than 0.5.

52. A toy glider according to claim 50 or 51, wherein at least part of the outer hull is swept with respect to the hull axis.

Claims

1. A submersible vehicle having an outer hull which defines a hull axis and appears substantially annular when viewed along the hull axis, the interior of the annulus defining a duct which is open at both ends so that when the vehicle is submerged in a liquid, the liquid floods the duct, wherein at least part of the outer hull is swept with respect to the hull axis.

2. A vehicle according to claim 1 wherein at least part of the outer hull is swept forward with respect to the hull axis.

3. A vehicle according to claim 1 or 2 wherein at least part of the outer hull appears swept with respect to the hull axis when viewed in plan and when viewed from the side.

4. A vehicle according to any preceding claim wherein the outer hull has a swept-forward shape when viewed in a first direction and a swept-back shape when viewed in a second direction transverse to the first direction.

5. A vehicle according to any preceding claim wherein at least part of the outer hull has a leading edge which is swept with respect to the hull axis and a trailing edge which is swept with respect to the hull axis.

6. A vehicle according to any preceding claim wherein the outer hull appears substantially circular when viewed along the hull axis.

7. A vehicle according to any preceding claim wherein the outer hull has a swept forward portion and a swept back portion.

8. A vehicle according to any preceding claim wherein the vehicle can modify its centre of buoyancy location by adjustment of a buoyancy engine along a ring that sits within the outer hull and follows the hull's swept shape.

9. A vehicle according to any preceding claim wherein the vehicle can modify its centre of gravity location by adjustment of mass along a ring that sits within the outer hull and follows the hull's swept shape, to effectively move the centre of gravity forward or earwards and consequently to induce pitch up or pitch down attitudes.

10. A vehicle according to any preceding claim wherein the hull has four bow vertices and four stem vertices which are separated by 90 degrees around the periphery of the hull.

11. A vehicle according to any preceding claim further comprising one or more pressure vessels housed inside the outer hull, wherein at least one of the pressure vessels appears substantially annular when viewed along the hull axis.

12. A vehicle according to any preceding claim wherein the vehicle has a center of gravity located in the duct and a center of buoyancy located in the duct.

13. A method of operating a vehicle according to any preceding claim, the method comprising: submerging the vehicle in a liquid whereby the liquid floods the duct, and rolling the vehicle about its hull axis.

14. The method of claim 13 wherein motive force for the vehicle is derived from a buoyancy engine that changes its state only twice during each dive and rise cycle.

15. A submersible toy glider having an outer hull which defines a hull axis and appears substantially annular when viewed along the hull axis, the interior of the annulus defining a duct which is open at both ends so that when the toy glider is submerged in a liquid, the liquid floods the duct, wherein at least part of the outer hull is swept with respect to the hull axis.