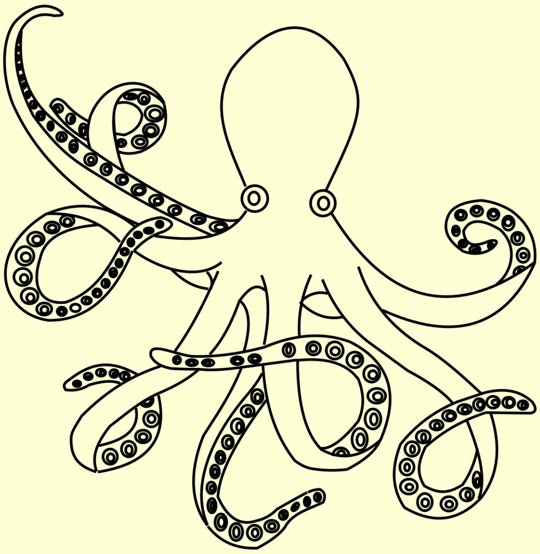

Diving & ROV specialists

Surface-Supplied Diving Handbook Series

Book #5

Managing weather, communications, surface supports & underwater vehicles

June 2025

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This document is the fifth of eight books in the "Surface-Supplied Diving Handbooks Series", described below.

Book 1: Overview of surface-supplied diving operations and scope of this series
Book 2: Description and prevention of accidents associated to diving operations
Book 3: Legal aspects of project preparation
Book 4: Description and maintenance of surface supplied diving systems
Book 5: Managing Weather, Communications, Surface Supports & Underwater Vehicles
Book 6: Prepare and manage the dives
Book 7: Implement the MT 92 tables
Book 8: Implement the DCIEM tables

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1 - Weather and currents

Among reported diving incidents/accidents, a lot were due to adverse environmental conditions not sufficiently anticipated. This is the reason why the supervisor must be sure that everything is under control on this side. For that, a minimum knowledge and good common sense is necessary.

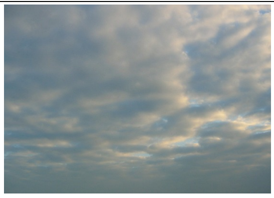
1.1 - Observe and report the weather

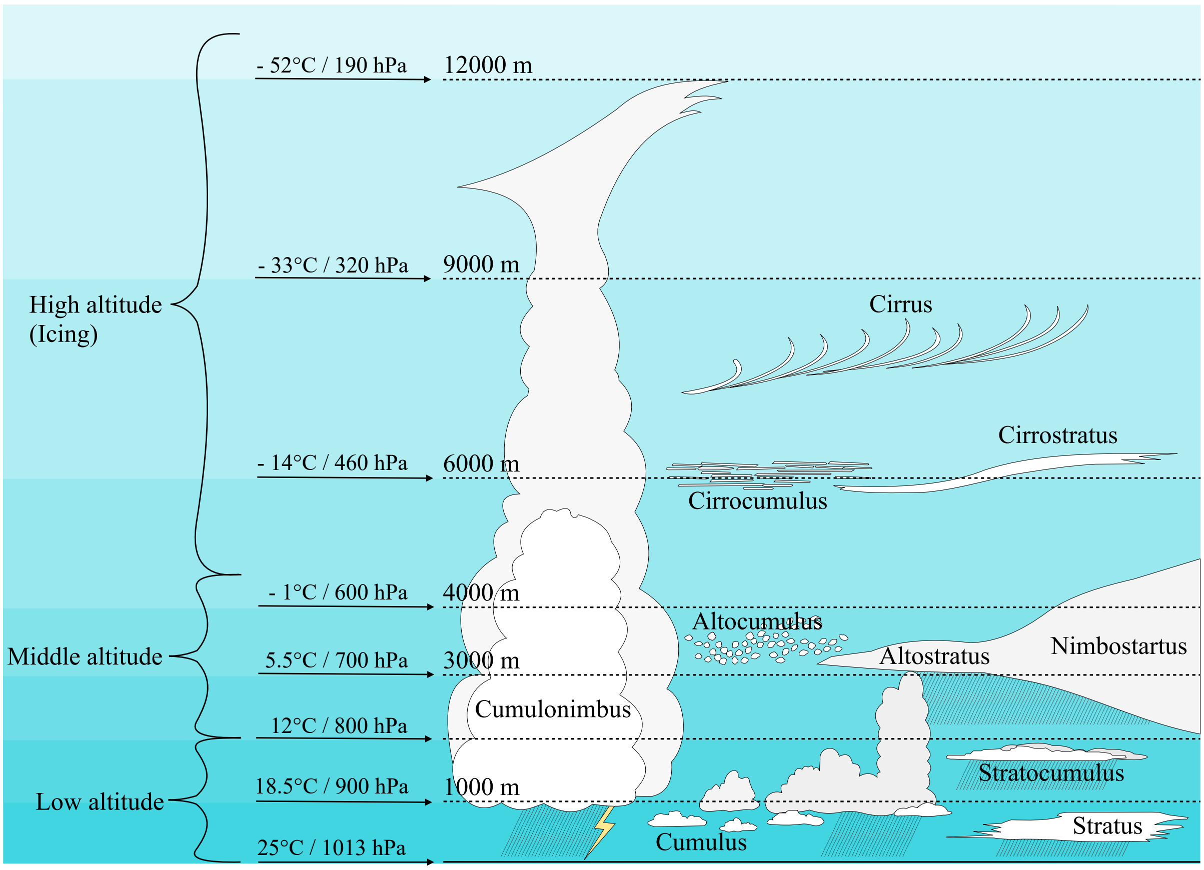
The weather prediction techniques have widely progressed with the development of means of calculation, communications and observation, particularly the space industry. Nevertheless, despite the obvious progress, experience sometimes shows some huge differences with the reality on location. That is why it is important to be able to observe and report clearly what is really happening on site. For that, the means of observation and the classifications developed in the old times are still valid tools.

1.1.1 - Clouds

In addition to the barometer, and the observation of the sea, the "reading" of the clouds is a reliable means of weather prediction.

Altitude	Name	Description
4000 to 12000 m	Cirrus	Cirrus clouds are formed when water vapor undergoes deposition at high altitudes. Random, isolated cirrus do not have any particular significance, but a large number of cirrus clouds can be a sign of an approaching frontal system or upper air disturbance. When cirrus clouds precede a cold front, squall line or multi-cellular thunderstorm, it is because they have been blown off the top of the cumulonimbus, and the next to arrive are the cumulonimbus clouds. In the tropics, a veil of white cirrus can be seen about 1 and a half days prior the passage of a cyclone. 
4000 to 6000 m	Cirrostratus	As a warm front approaches, cirrus clouds tend to thicken into cirrostratus. When sunlight or moonlight passes through the hexagonal-shaped ice crystals of cirrostratus clouds, the light is dispersed or refracted in such a way that a ring or halo may form. Cirrostratus may thicken and lower into altostratus, stratus, and even nimbostratus. 
3000 to 6000 m	Cirrocumulus	Cirrocumulus clouds are layered clouds which commonly appear in regular, rippling patterns or in rows of clouds with clear areas in between. Like other members of the cumuliform category, they are formed via convective processes. Significant growth of these patches indicates high-altitude instability and can signal the approach of poorer weather. 
2000 to 6000 m	Altocumulus	They are characterized by globular masses or rolls in layers or patches. They are larger and darker than cirrocumulus and smaller than stratocumulus. Altocumulus are commonly found between the warm and cold fronts in a depression, often hidden by lower clouds. Towering altocumulus, frequently signals the development of thunderstorms later in the day, as it shows instability and convection in the middle levels of the troposphere. 
2000 to 4000 m	Altostratus	An altostratus is formed by the lifting of a large mostly, stable air mass that causes invisible water vapour to condense into clouds. It can produce light precipitation. If the precipitation increases in persistence and intensity, the altostratus cloud may thicken into nimbostratus. 
2000 to 4000 m	Nimbostratus	Nimbostratus clouds belong to the Low Cloud group. They are dark grey with a ragged base. Nimbostratus clouds are associated with continuous rain (or snow). Sometimes they cover the whole sky, and you can't see the edges of the cloud. 

Altitude	Name	Description
2000 to 2400 m	Stratocumulus	They are large dark, rounded clouds, usually in groups, lines, or waves. Larger than the altocumulus, and at a lower altitude. When they produce precipitation, it is only light rain (or snow). However, these clouds are often seen at either the front or tail end of worse weather, so they may indicate storms to come. They are also often seen underneath the cirrostratus and altostratus sheets that often precede a warm front. 
1000 to 3000 m	Cumulus	They are low-level clouds that can have noticeable vertical development and clearly defined edges. They are "cotton-like" in appearance, and generally have flat bases. Cumulus clouds may appear by themselves, in lines, or in clusters. They can be associated with good or bad weather.   Cumulus humilis clouds (photo on the right) are associated with fair weather. Cumulus congestus clouds (Photo on the left) are often precursors of other types of clouds such as cumulonimbus, and usually associated with bad weather. Their tops look like cauliflower heads and mean that light to heavy showers can occur.
Surface to 2000 m	Stratus	These clouds belong to the Low Cloud group which form when a sheet of warm, moist air lifts off the ground and depressurises, or when the ambient air temperature decreases, increasing the relative humidity. They can also form from stratocumulus. They are uniform grey in colour and can cover most or all of the sky, and look like a fog that doesn't reach the ground. They can persist for days in anticyclone conditions. 
1000 to 12000 m	Cumulonimbus	Cumulonimbus clouds belong to the Clouds with Vertical Growth group. They are generally known as thunderstorm clouds. A cumulonimbus cloud can grow up to 12 km high. At this height, high winds will flatten the top of the cloud out into an anvil-like shape. Cumulonimbus clouds are associated with heavy rain, (snow & hail), lightning, and tornadoes. Cumulonimbus progress from overdeveloped cumulus congestus clouds and may further develop as part of a supercell. 



Note: To be more realistic with the tropical areas, the temperatures are calculated for 25 degrees at the surface instead of 15 degrees commonly used for the Standard Atmosphere.

1.1.2 - Beaufort scale

Invented by Admiral Beaufort (1774 - 1857), it is an empirical system of measure based on the observation of the sea state and the wind speed: This system allows to identify the condition of the sea with reduced tools.

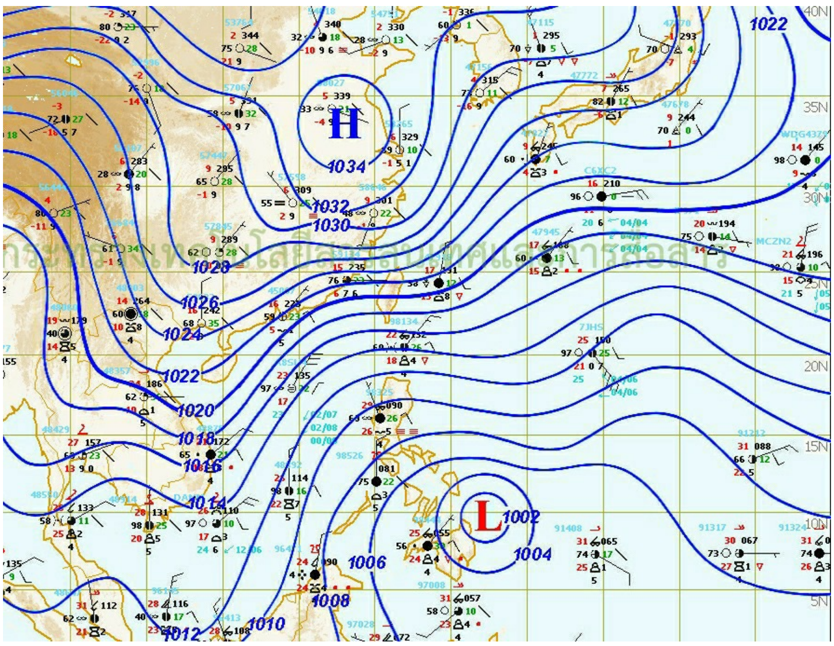
Force (level)	Wind speed (kts)	Waves height	Description	Visual effect
0	0	0	Calm	Sea like a mirror
1	1	0.1	Light air	Ripples with the appearance of scales are formed, but without foam crests
2	4	0.2	Light breeze	Small wavelets, still short but more pronounced; crests have a glassy appearance and do not break
3	7	0.6	Gentle breeze	Large wavelets; crests begin to break; foam of glassy appearance; perhaps scattered white horses
4	11	1	Moderate breeze	Small waves, becoming longer; fairly frequent white horses
5	17	1.8	Fresh breeze	Moderate waves, taking a more pronounced long form; many white horses are formed
6	22	3	Strong breeze	Large waves begin to form; the white foam crests are extensive everywhere
7	28	4	Near gale	Sea heaps up and white foam from breaking waves begins to be blown in streaks along the direction of the wind
8	34	5.5	Gale	Moderately high waves of greater length; edges of crests begin to break into spindrift; foam
9	41	7	Strong gale	High waves; dense streaks of foam along the direction of the wind; crests of waves begin to topple.
10	46	9	Storm	Very high waves with long overhanging crests; the surface of the sea takes a white appearance; visibility affected
11	56	11	Violent storm	Exceptionally high waves; the sea is completely covered with long white patches of foam; visibility affected
12	64	14 & +	Hurricane	The air is filled with foam and spray; sea completely white with driving spray; visibility seriously affected

1.1.3 - Barometer

A barometer is still used by the forecasters to measure the short term changes. There is a barometer on any boat, and regular records can be helpful to predict the tendency, and also cross check with the indications of the weather maps.

The normal atmospheric pressure at sea level is 760 mm of mercury (also called Torr) which is corresponding to 1013 hecto-Pascal (noted hPa).

- The pressures below 1013 hPa are considered as low. They are indicated on the weather maps by a "L".
- The pressures Above 1013 hPa are considered high pressure and they are indicated on the map using a "H".
- Notice that some forecasters call the low pressure zones "depression" and the high pressure zone "Anticyclone". In this case, they are noted using a "D" in place of "L" and an "A" in place of "H".
- The levels of pressures recorded are indicated on the weather maps using blue or black lines.



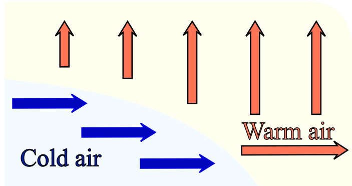
1.2 - Weather systems

1.2.1 - Global system

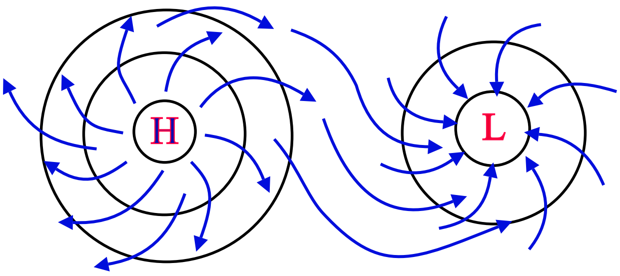
The weather systems are driven by the heat received from the sun at the Earth's surface. Because roughly spherical, with an orientation and a distance from the sun which change during the year, the distribution of heat on earth is not uniform, and varies during the year (it is what we call the seasons). Also, oceans and land absorb heat in different ways. Over oceans, the air temperature remains relatively stable for two reasons: water has a relatively high heat capacity, and because both conduction and convection will equilibrate a hot or cold surface with deeper water. In contrast, dirt, sand, and rocks have lower heat capacities, and they can only transmit heat into the Earth by conduction and not by convection. Therefore, bodies of water stay at a more even temperature, while land temperatures are more variable.

The heat at the surface of land or the sea is transmitted to the atmosphere and creates what is called “air masses”. An air mass is often defined as a widespread body of air that is approximately homogeneous in its horizontal extent, particularly with reference to temperature and moisture distribution; in addition, the vertical temperature and moisture variations are approximately the same over its horizontal extent. The stagnation or long-continued motion of air over a source region permits the vertical temperature and moisture distribution of the air to reach relative equilibrium with the underlying surface: For example, polar air masses are cold and equatorial air masses warm. Air masses over land are usually dry and those above the ocean are moist.

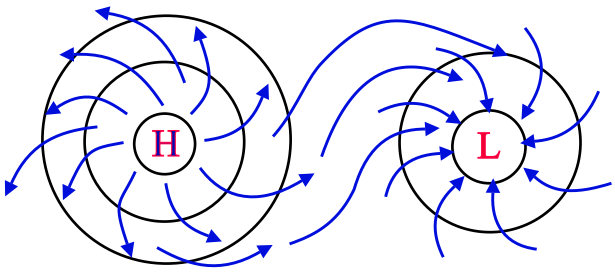
Because the hot air masses are warmer, they expand, and areas of low pressure develop. Meanwhile, the air masses which remain at lower temperatures retain higher pressures. These differences in pressure cause air movements.



Air naturally flows from high to low pressure; but the “coriolis force” due to the rotation of the Earth, deflect the flow. As a result, in the North Hemisphere, the air from an anticyclone (high pressure) flows clockwise, slightly outwards across the isobars at an angle of about 18°–20°, and blows anticlockwise slightly inwards across the isobars, at an angle of about 10°–20° when approaching a depression. In the South Hemisphere, the circulations are reversed with air diverging in an anticlockwise flow around an anticyclone and converging in a clockwise circulation around a depression. These angles across the isobar are due to the frictions with the environment.

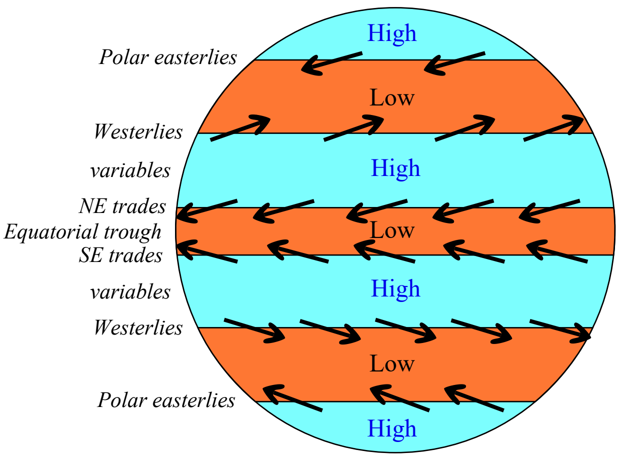


North Hemisphere



South Hemisphere

Over surfaces free of obstruction, this system should create pressure belts with associated preferential winds, but in reality these belts are disturbed by the land masses. The description of the system is as follows:



- Equatorial trough

The “Equatorial Trough” or “Doldrums” is a low pressure belt of small gradients. It moves N and S seasonally outside the equatorial latitudes, particularly in the vicinity of large land masses. These areas where the Trade Winds from the two hemispheres converge are marked by lines or zones of massive cumulonimbus clouds and associated heavy downpours, thunderstorms and squalls, and are also named the “Inter-tropical Convergence Zone”. The weather to be expected in the fine weather. The conditions are generally degraded when the Trade Winds are strong. This zone is often the birthplace of disturbances which can develop and intensify to become violent tropical storms.

- Trade winds

These winds blow from the sub-tropical oceanic anticyclones (HP) of the N and S Hemispheres towards the "Equatorial Trough". The general direction is NE in the N Hemisphere; SE in the S Hemisphere. They blow persistently over all major oceans of the world, except the North Indian Ocean and the China Seas where the monsoon winds predominate. The zones where they blow follow the migration of the Equatorial trough. Their average speed is between 7 to 16 knots with a maximum strength of 20 knots in the spring. The weather in these zones is generally favourable with clear sky or only small clouds. Mist, fog and impaired visibility can be encountered due to cold ocean currents or dust carried by the wind. The clouds and rain increase towards the "Equatorial Trough" and also near the Westerlies in summer.

Variables:

"Variable" are the zones covered by the oceanic anticyclones between the "Trade Winds" and the "Westerlies". The winds of these areas are light with fair weather and small amounts of rain.

- Westerlies

They are the areas between 30 and 60 degrees latitude with prevailing winds blowing from the high pressure area in the horse latitude towards the poles from the west to the east. Because there are continual passages of depressions across these zones, the winds vary in direction and strength but they are predominantly from the southwest in the Northern Hemisphere and from the Northwest in the Southern Hemisphere. Gales are frequent, especially in winter, and particularly in the 40° of the South Hemisphere (Roaring Forties). Due to these conditions, the weather changes rapidly and fine weather is seldom prolonged.

- Polar Easterlies

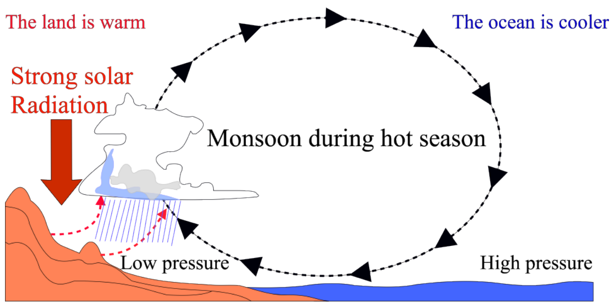
These prevailing winds are generally from the east. Gales are common in winter often accompanying snow or ice rains . Cloudy sky and fog is frequent in summer. These areas are difficult to access or unreachable by boat due to the amount of ice.

1.2.2- Seasonal system: The monsoon

Monsoons are large-scale sea breezes which occur when the temperature on land is significantly warmer or cooler than the temperature of the ocean. "Monsoon" is traditionally defined as a seasonal reversing winds accompanied by corresponding changes in precipitation, and usually refers to the rainy phase, but technically there is also a dry phase.

- Hot season

During the warmer months, the sunlight heats the surfaces of both land and oceans, but land temperatures rise more quickly. As the land's surface becomes warmer, the air above it expands and an area of low pressure develops. Meanwhile, the ocean remains at a lower temperature than the land, and the air above it retains a higher pressure. This difference in pressure causes sea breezes to blow from the ocean to the land, bringing moist air inland. This moist air rises to a higher altitude over land and then it flows back toward the ocean (thus completing the cycle). However, when the air rises, and while it is still over the land, the air cools. This decreases the air's ability to hold water, and this causes precipitation over the land. This is why summer monsoons cause so much rain over land.

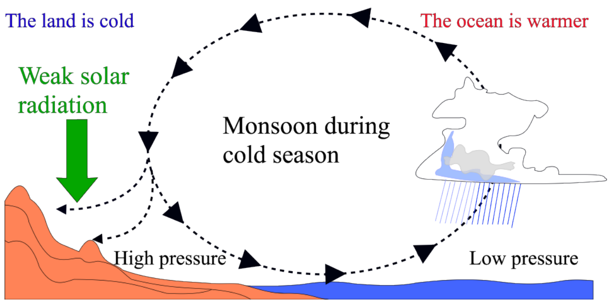


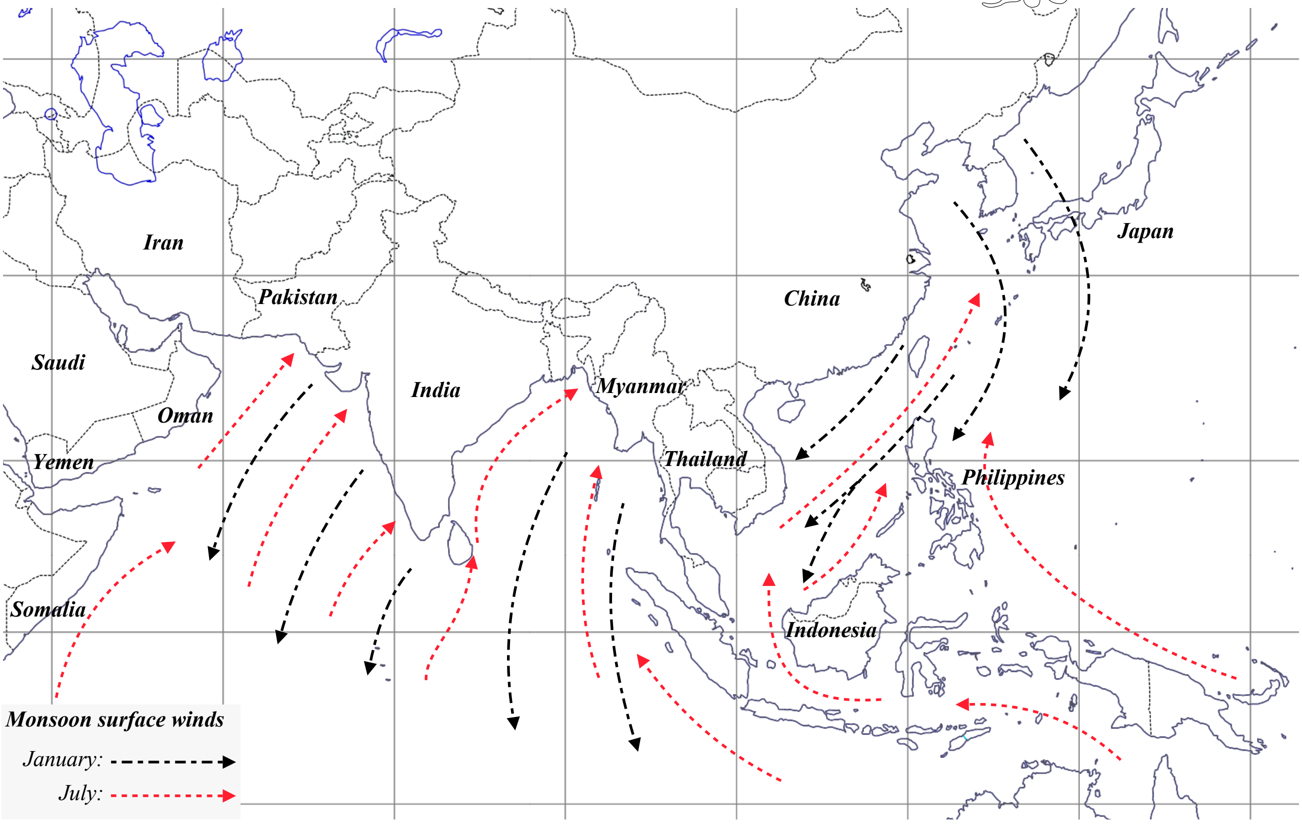
As result, in the North, the pressure over Asia falls with lowest pressure near the West Himalayas. The anticlock-wise circulation gives persistent Southwest Monsoon winds from May to September or October over the North Indian Ocean and South China Sea, and South Southwest or South winds over the West Pacific Ocean. Winds are generally fresh to strong and raise considerable seas. Warm humid air gives much cloud and rain on windward coasts and islands.

- Cold season

In the colder months, the cycle is reversed. The land cools faster than the oceans and the air over the land has higher pressure than air over the ocean. This causes the air over the land to flow to the ocean. When humid air rises over the ocean, it cools, and this causes precipitation.

As result, in the North, an intense anticyclone (high pressure zone) develops over the cold Asian continent and from around October or November to March a persistent North-east Monsoon wind blows over the North Indian Ocean and South China Sea; over the West Pacific Ocean the wind is North Northeast. The winds are generally moderate to fresh but can reach gale force locally as surges of cold air move South and particularly where funneling effects occurs (Taiwan Strait, Palk Strait, for example).



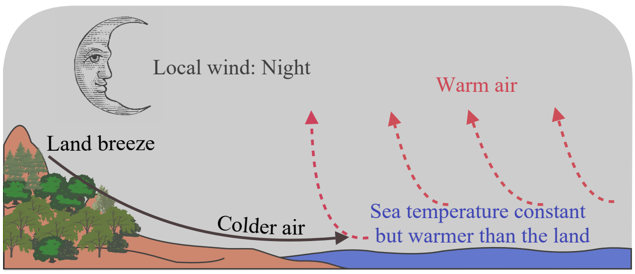


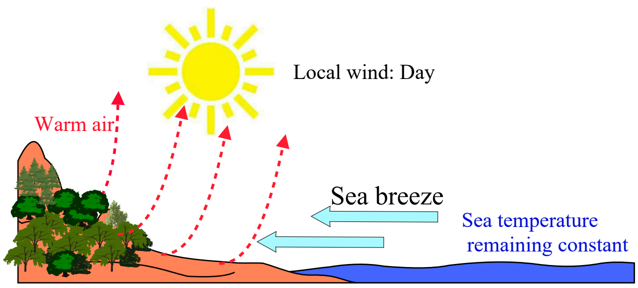
1.2.3 - Local system: Land and sea breeze

The cause of these breezes is the unequal heating and cooling of the land and sea. By day, the sun rapidly raises the temperature of the land surface whereas the sea temperature remains virtually constant. Air in contact with the land expands and rises, and air from the sea flows in to take its place producing an onshore wind known as a “sea breeze”. By night, the land rapidly loses heat by radiation and becomes colder than the adjacent sea; air over the land is chilled and flows out to sea to displace the warmer air over the sea and produces the offshore wind known as a “land breeze”. Sea breezes usually set in during the forenoon and reach maximum strength, about force 4 (occasionally 5 or 6) in mid-afternoon. They die away around sunset. Land breezes set in late in the evening and fade shortly after sunrise; they are usually weaker and less well marked than sea breezes. The following factors favour development of land and sea breezes:

- Clear or partly cloudy skies;
- Calm conditions or light variable winds;
- Desert or dry barren coast as opposed to forests or swamps;
- High ground near the coast.

In windy conditions, the effect of a land or sea breeze may be to modify the prevailing wind by reinforcing, opposing or causing a change in direction.





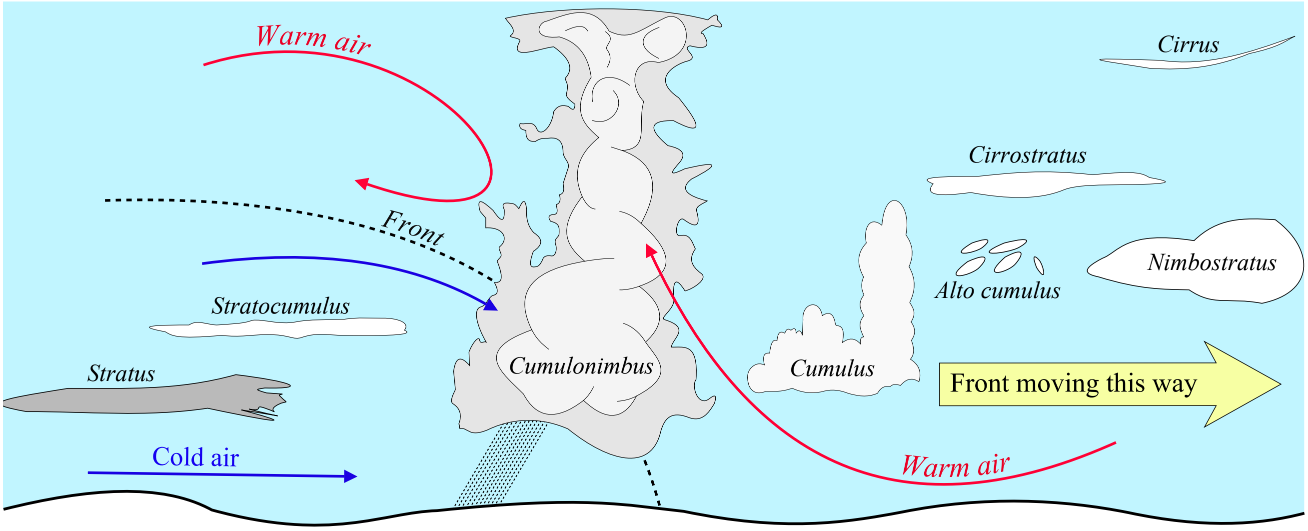
1.3 - Weather perturbations

1.3.1 - Weather front

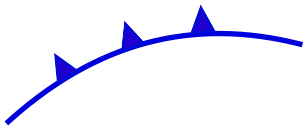
A weather front is a boundary separating two masses of air of different densities, and humidity. It is the principal cause of meteorological phenomena.

- Cold weather front

A cold weather front is due to a cold air mass replacing a warmer air mass. The air behind a cold front is colder and drier than the air in front. Cold fronts generally move from west to east. A cold front approaching is commonly generating strong winds with a sudden drop in temperature and heavy rain. Lifted warm air ahead of the front produces cumulus or cumulonimbus clouds and thunderstorms, often preceded by cirrus, cirrostratus then altostratus and altocumulus. Atmospheric pressure changes from falling to rising at the front. After a cold front moves through an area it may be noticed that the temperature is cooler, the rain has stopped, and the cumulus clouds are replaced by stratus and stratocumulus clouds or clear skies. Because of the greater density of air in their wake, cold fronts and cold occlusions move faster than warm fronts and warm occlusions.

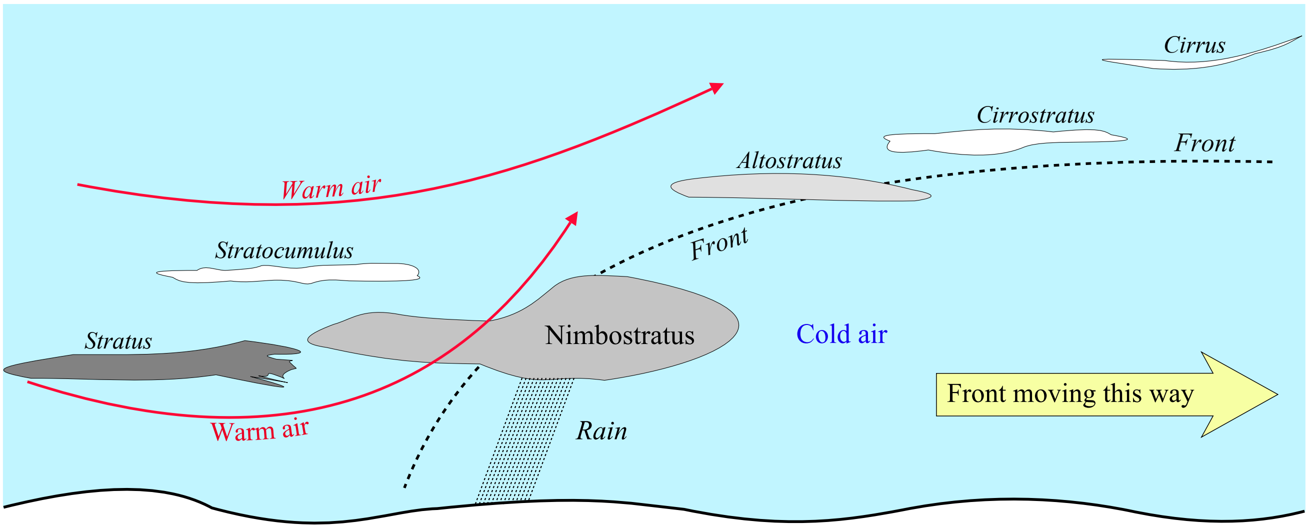


On a weather forecast map, a cold front is represented by a solid line with blue triangles along the front pointing towards the warmer air and in the direction of movement.

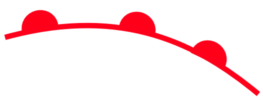


- *Warm front*

A warm weather front is defined as a warm air mass replacing a cold air mass. Warm fronts usually move from southwest to northeast and the air behind a warm front is warmer and moister than the air ahead of it. When a warm front passes, the air becomes noticeably warmer and more humid than it was before. High clouds like cirrus, cirrostratus, and middle clouds like altostratus are ahead of a warm front. These clouds form in the warm air that is high above the cool air. As the front passes over an area, the clouds become lower and rain and sometimes fog is likely. There can be thunderstorms around the warm front if the air is unstable. The weather usually clears with scattered stratus and stratocumulus. If the warm front is part of a depression, there is often a sheet of altostratus.



On a weather forecast map, a warm front is represented by a solid line with red semicircles pointing towards the colder air and in the direction of movement.

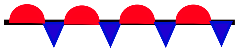


- *Stationary front*

A stationary front forms when a cold front or warm front stops moving. This happens when two masses of air are pushing against each other but neither is powerful enough to move the other. Winds blowing parallel to the front instead of perpendicular can help it stay in place. Stationary fronts may stay put for days. If the wind direction changes the front will start moving again, becoming either a cold or warm front, or the front may break apart.

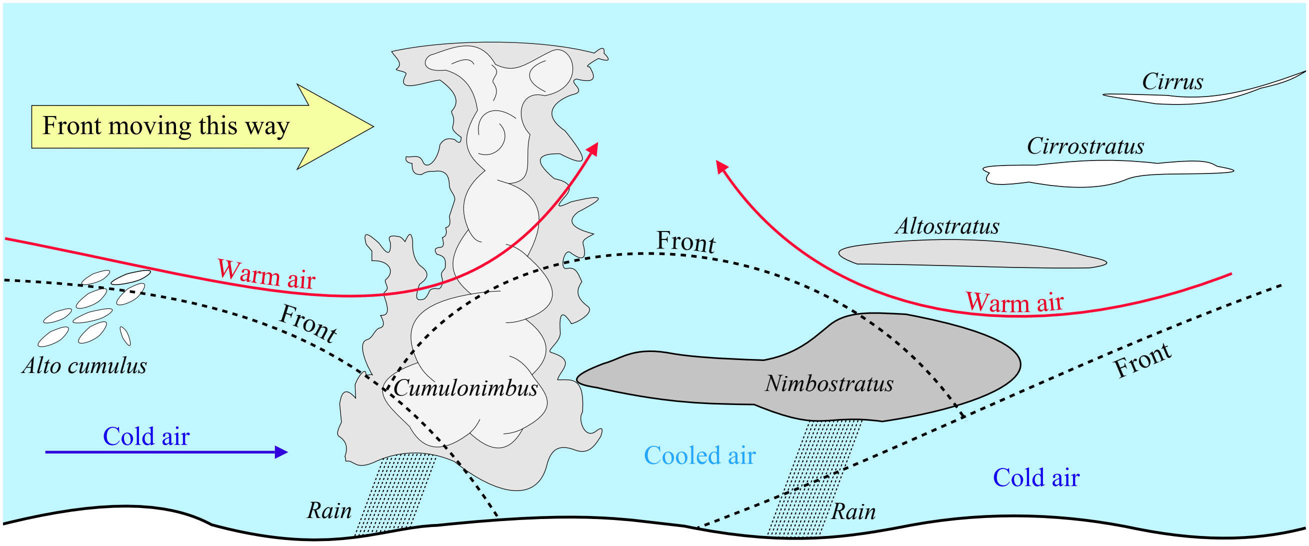
Because a stationary front marks the boundary between two air masses, there are often differences in air temperature and wind on opposite sides of it. The weather is often cloudy along a stationary front and rain often falls, especially if the front is in an area of low atmospheric pressure. Over time, the density contrast across the frontal boundary vanishes. This is most common over the open oceans. The temperature of the ocean surface is usually the same on both sides of the frontal boundary and modifies the air masses on either side of it to correspond to its own temperature.

On a weather map, a stationary front is shown as alternating red semicircles and blue triangles like in the map on the right. The blue triangles point in one direction and the red semicircles point in the opposite direction.

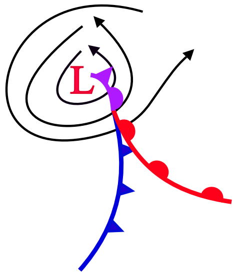


- Occluded front

Sometimes a cold front follows right behind a warm front. A warm air mass pushes into a colder air mass (the warm front) and then another cold air mass pushes into the warm air mass (the cold front). Because cold fronts move faster, the cold front is likely to overtake the warm front. Occluded fronts usually form around areas of low atmospheric pressure.
There is often precipitation along an occluded front from cumulonimbus or nimbostratus clouds with more severe weather than the weather found in a cold front. Wind changes direction as the front passes, and the temperature changes too. The temperature may warm or cool. After the front passes, the sky is usually clearer and the air is drier.



On a weather map, an occluded front looks like a purple line with triangles and semicircles along it pointing in the direction that the front is moving. It ends at a low pressure area shown with a large 'L' on the map, and at the other end connects to cold and warm fronts. (See on the right)



1.3.2 - Wind gust & squall

Wind gust is a sudden, brief increase in speed of the wind which reaches at least 16 knots, and the variation in wind speed between the peaks and lulls is at least 9 knots. The duration of a gust is usually less than 20 seconds.
A squall is a sudden, sharp increase in wind speed of 15 knots with a minimum speed of 21 knots which is usually associated with active weather, such as rain showers and thunderstorms.

1.3.3 - Thunderstorm

Thunderstorms are dangerous phenomena which form when very warm, moist air rises into cold air. As this humid air rises, water vapour condenses, forming huge cumulonimbus clouds.

There are two main types of thunderstorms: ordinary and severe.

- Ordinary thunderstorms last about one hour. The precipitation associated with these storms includes rain. With ordinary thunderstorms, cumulonimbus clouds can grow up to 12 kilometers high.
- Severe thunderstorms is a term designating a thunderstorm that has reached a predetermined level of severity. They are generally large, and capable of producing baseball-size hail (25 mm Ø and above), strong winds (at least 93 km/h) , intense rain (> 50 mm / hr, or 75 mm for 3 hrs), flash floods, and tornadoes. Severe thunderstorms can last several hours and can grow 18 kilometers high. These phenomenon can occur from any type of storm cell. However, three common forms of thunderstorms are the most frequently involved in severe weather:
  - "Multicell" thunderstorms, which are clusters of storms that may then evolve into one
  - "Supercell" which are large thunderstorms, also referred to as rotating thunderstorms
  - "Squall lines" are lines of thunderstorms that can form along or ahead of a cold front

- Thunderstorm formation

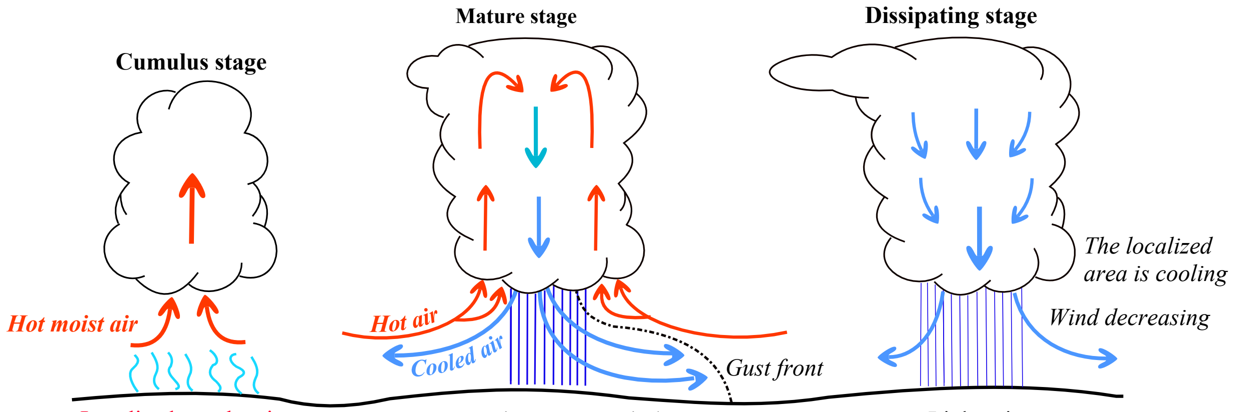
Most thunderstorms develop from a cycle that has three stages: the cumulus stage, mature stage, and dissipating stage.

Cumulus Stage
The sun heats the Earth's surface during the day. The heat on the surface warms the air around it. Since warm air is lighter than cool air, it starts to rise (known as an updraft). If the air is moist, then the warm air condenses into a cumulus

cloud. The cloud will continue to grow as long as warm air below it continues to rise.

Mature Stage:
When the cumulus cloud becomes very large, the water in it becomes large and heavy. Raindrops start to fall through the cloud when the rising air can no longer hold them up. Meanwhile, cool dry air starts to enter the cloud. Because cool air is heavier than warm air, it starts to descend in the cloud (known as a downdraft). The downdraft pulls the heavy water downward, making rain.
This cloud has become a cumulonimbus cloud because it has an updraft, a downdraft, and rain. Thunder and lightning start to occur, as well as heavy rain. The cumulonimbus is now a thunderstorm cell.

Dissipating Stage:
After about 30 minutes, the thunderstorm begins to dissipate. This occurs when the downdrafts in the cloud begins to dominate over the updraft. Since warm moist air can no longer rise, cloud droplets can no longer form. The storm dies out with light rain as the cloud disappears from bottom to top.
The whole process takes about one hour for an ordinary thunderstorm. Supercell thunderstorms are much larger, more powerful, and last for several hours.



Lightning:
Lightning is a giant spark. A single stroke of lightning can heat the air around it to 30,000 degrees Celsius. This extreme heating causes the air to expand at an explosive rate. The expansion creates a shock wave that turns into a booming sound wave known as thunder.

1.3.4 - Tropical cyclones

"Cyclone" is the scientific name referring to hurricane, typhoon, tropical storm, cyclonic storm, and tropical depression. It is a rapidly-rotating storm system characterized by a low-pressure centre, strong winds, and a spiral arrangement of thunderstorms that produce heavy rain. Depending on its location and strength, they are usually characterized by inward spiraling winds that rotate anti-clockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere of the Earth.
Tropical cyclones typically form over large bodies of relatively warm water. They derive their energy from the evaporation of water from the ocean surface, which ultimately recondenses into clouds and rain when moist air rises and cools to saturation. In fact, the process is similar to thunderstorms.
The first indicator of cyclone development is the appearance of a cluster of thunderstorms over the sea. There are six main requirements to develop a tropical cyclone:

- Sufficiently warm sea surface temperatures
- Atmospheric instability
- High humidity in the lower to middle levels of the troposphere (Troposphere = Surface to 17- 20 km above)
- Enough "Coriolis force" to develop a low pressure centre
- A preexisting low level disturbance
- A low vertical wind shear

With strong cyclones, the Coriolis force initiated by the rotation of Earth causes the resulting low-level winds to spiral anticlockwise in the Northern Hemisphere, and clockwise in the Southern Hemisphere.
The cyclones are classified into 3 main groups based on the intensity:

- Tropical depression
It is an organized system of clouds and thunderstorms with a defined, closed surface circulation and maximum sustained winds of less than 34 knots (63 km/h). It has no eye and does not typically have the organization or the spiral shape of more powerful storms. However, it is a low-pressure system, hence the name "depression".

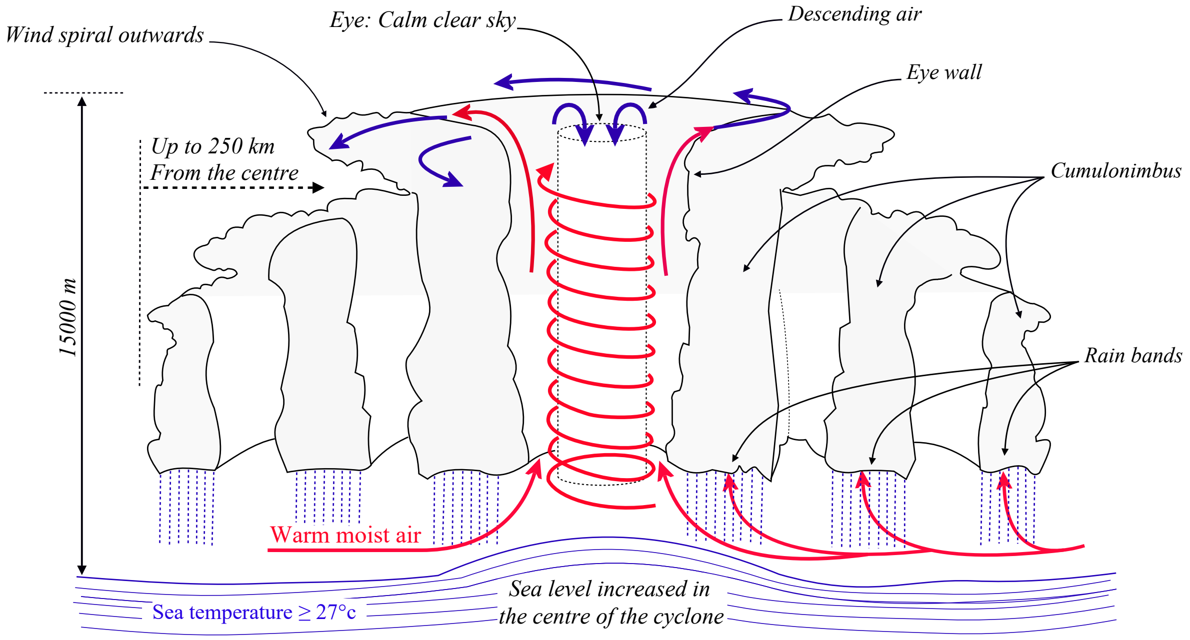
- Tropical storm
It is an organized system of strong thunderstorms with a defined surface circulation and maximum sustained winds between 34 knots (63 km/h) and 64 knots (118 km/h). At this point, the distinctive cyclonic shape starts to develop, although an eye is not usually present.

- *Tropical cyclone or hurricane (also called typhoon)*

Tropical cyclones are typically between 100 and 4000 km in diameter. A cyclone is considered a "hurricane" when the wind speed reaches 119 km/h (64.3 knots). A cyclone of this intensity tends to develop an eye, visible from satellite, which is an area of relative calm and lowest atmospheric pressure at the centre of circulation. Surrounding the eye is the eye-wall, an area about 16 to 80 kilometres wide in which the strongest thunderstorms and winds circulate around the storm's centre. Maximum sustained winds in the strongest tropical cyclones are about 165 knots/h (314 km/h).

A "tropical cyclone" or "hurricane" works like a large heat engine: The fuel is moisture from warm ocean water. The moisture is converted to heat in the thunderstorms that form. Spiral rain bands that surround the tropical cyclone's core help feed the circulation more heat energy. As air nears the centre, it rises rapidly and condenses into clouds and rain. The condensation releases tremendous amounts of heat into the atmosphere. The result is lower surface pressure and strengthening winds.

In this way, the tropical cyclone's engine refuels itself, concentrating its power in a donut-shaped area, called the eye wall, surrounding the centre. The eye wall typically contains the strongest surface winds. Sinking air at the centre clears the tropical cyclone of clouds and forms the "eye." Falling surface pressure can occur only if air mass is removed from the circulation centre. This is accomplished by wind flowing away from the circulation in the upper atmosphere.



Based on wind speeds and damages caused on shore, hurricanes are categorised from 1 to 5 on "Saffir-Simpson" scale. This scale can be used offshore to evaluate the potential damages to a boat and a dive system.

Category 1: Winds 119-153 km/hr**.** Storm surge generally 1.2-1.5 m (4-5 feet) above normal. No real damage to building structures. Damage primarily to unanchored mobile homes, shrubbery, and trees. Some damage to poorly constructed signs, and some coastal road flooding and minor pier damage

Category 2: Winds 154-177 km/hr. Storm surge generally 1.8-2.4 m (6-8 feet) above normal. Some roofing material, door, and window damage of buildings. Considerable damage to shrubbery and trees, with some trees blown down. Considerable damage to mobile homes, poorly constructed signs, and piers. Coastal and low-lying escape routes flood 2-4 hours before arrival of the hurricane center.

Category 3: Winds 178-209 km/h. Storm surge generally 2.7-3.6 m (9-12 ft) above normal. Some structural damage to small residences and utility buildings, with a minor amount of curtain wall (non-load-bearing exterior wall) failures. Damage to shrubbery and trees, with foliage blown off trees, and large trees blown down. Mobile homes and poorly constructed signs are destroyed. Low-lying escape routes are cut by rising water 3-5 hours before arrival of the centre of the hurricane. Flooding near the coast destroys smaller structures, with larger structures damaged by battering from floating debris.

Category 4: Winds 210-249 km/hr (131-155 mph). Storm surge generally 3.9-5.5 m (13-18 feet) above normal. More extensive curtain wall failures, with some complete roof structure failures on small residences. Shrubs, trees, and all signs are blown down. Complete destruction of mobile homes. Extensive damage to doors and windows. Low-lying escape routes may be cut by rising water 3-5 hours before arrival of the centre of the hurricane. Major damage to lower floors of structures near the shore. Terrain lower than 10 feet above sea level may be flooded

Category 5: Winds greater than 249 km/hr (155 mph). Storm surge generally greater than 5.5 m (18 feet) above normal. Complete roof failure on many residences and industrial buildings. Some complete building failures, with small utility buildings blown over or away. All shrubs, trees, and signs blown down. Complete destruction of mobile homes. Severe and extensive window and door damage. Low-lying escape routes are cut by rising water 3-5 hours before arrival of the centre of the hurricane. Major damage to lower floors of all structures located less than 4.5 m (15 feet) above sea level and within 460 m (500 yards) of the shoreline.

- *Precursor signs offshore:*

British Admiralty says the following: The following signs may be evidence of a storm in the locality; the first of these observations is a very reliable indication of the proximity of a storm within 20° or so of the equator. It should be borne in mind, however, that very little warning of the approach of an intense storm of small diameter may be expected.

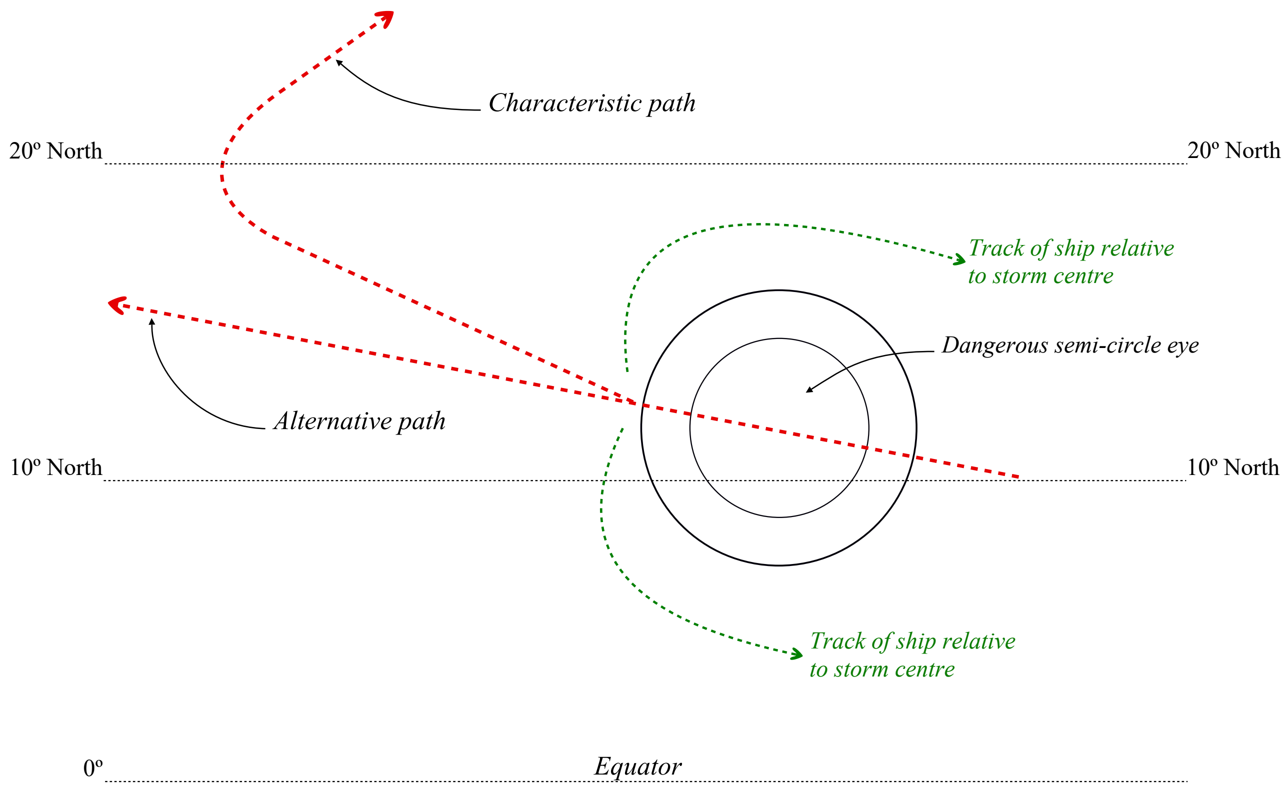
- If a corrected barometer reading is 3 hpa or more below the mean for the time of year, as shown in the climatic atlas or appropriate volume of *Admiralty Sailing Directions*, suspicion should be aroused and action taken to meet any development. The barometer reading must be corrected not only for height, latitude, temperature and index error (if mercurial) but also for diurnal variation which is given in climatic atlases or appropriate volumes of *Admiralty Sailing Directions*. If the corrected reading is 5 hPa or more below normal it is time to consider avoiding action for there can be little doubt that a tropical storm is in the vicinity. Because of the importance of pressure readings, it is wise to take hourly barometric readings in areas affected by tropical storms;
- An appreciable change in the direction or strength of the wind;
- A long low swell is sometimes evident, proceeding from the approximate bearing of the centre of the storm. This indication may be apparent before the barometer begins to fall;
- Extensive cirrus clouds followed, as the storm approaches, by altostratus and then broken cumulus or scud.
- Radar may give warning of a storm within about 100 miles. By the time the exact position of the storm is given by radar, the ship is likely to be already experiencing high seas and strong to gale force winds. It may be in time, however, to enable the ship to avoid the eye and its vicinity where the worst conditions exist.

- *Path of the storm:*

British admiralty also says: To decide the best course of action if a storm is suspected in the vicinity, the following knowledge is necessary:

  - The bearing of the centre of the storm.
  - The path of the storm.

- If an observer faces the wind, the centre of the storm will be from 100° to 125° on his right hand side in the N hemisphere when the storm is about 200 miles away, when the barometer has fallen about 5 hPa and the wind has increased to about force 6. As a rule, the nearer he/she is to the centre the more nearly does the angle approach 90°. The path of the storm may be approximately determined by taking two such bearings separated by an interval of 2–3 hours, allowance being made for the movement of the ship during the interval. It can generally be assumed that the storm is not traveling towards the equator and, if in a lower latitude than 20°, its path is most unlikely to have an E component. On the rare occasions when the storm is following an unusual path it is likely to be moving slowly.
- The diagram below shows typical paths of tropical storms and illustrates the terms dangerous and navigable semicircle. The former lies on the side of the path towards the usual direction of recurvature, the right hand semicircle in the N and the left hand semicircle in the S Hemisphere. The advance quadrant of the dangerous semicircle is known as the dangerous quadrant as this quadrant lies ahead of the centre. The navigable semicircle is that which lies on the other side of the path. A ship situated within this semicircle will tend to be blown away from the storm centre and recurvature of the storm will increase her distance from the centre.



In the North Hemisphere (See previous page)

a) If the wind is backing, the ship will be in the dangerous semi circle. The ship should proceed with all available speed with the wind 10 degrees - 45 degrees depending on speed on the port bow. As the wind backs the ship should alter course to port thereby tracing a course relative to the storm as shown in the diagram on the previous page

b) If the wind remains steady in direction or nearly steady so that the vessel should be in the path of the storm or very nearly in its path. She should bring the wind well on to the port quarter and proceed with all available speed. When well within the navigable semicircle act as at (c) below.

c) If the is wind backing the ship is in the navigable semicircle. The ship should bring the wind on the starboard quarter and proceed with all available speed turning to port as the wind backs to follow a track as shown in the diagram.

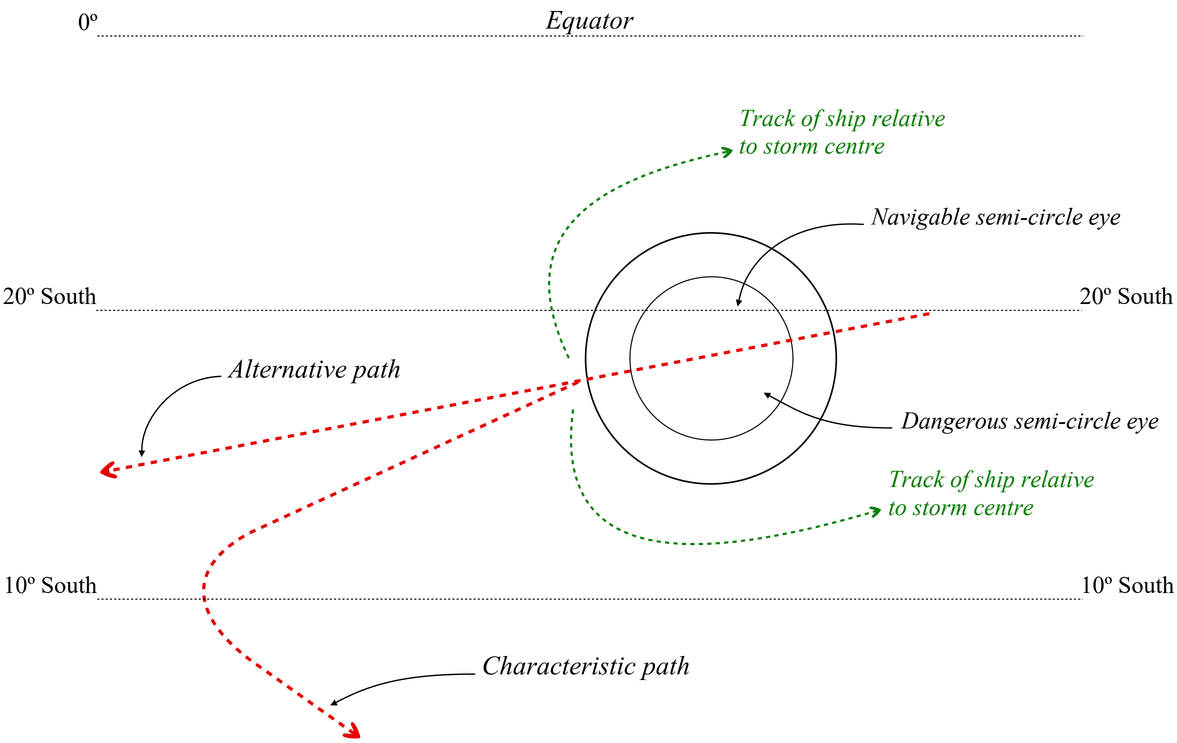
In the South Hemisphere (see below)

a) If the wind backing, the ship must be in the dangerous semicircle. The ship should proceed with all available speed with the wind 10 degrees – 45 degrees, depending on speed, on the port bow. As the wind backs, the ship should alter course to port thereby tracing a course relative to the storm as shown in diagram below.

b) If the wind remains steady in direction, or nearly steady, so that the vessel should be in the path of the storm or very nearly in its path, she should bring the wind well on to the port quarter and proceed with all available speed. When well within the navigable semicircle act as at (*c*) below.

c) If the wind veers, the ship is in the navigable semicircle. The ship should bring the wind on to the port quarter and proceed with all available speed turning to starboard as the wind veers to follow a track as shown in the diagram.

If there is insufficient room to run when in the navigable semicircle and it is not practicable to seek shelter, the ship should heave-to with the wind on her starboard bow in the N hemisphere or on her port bow in the S hemisphere.



- *In the harbour*

British admiralty also says that when a tropical storm approaches it is preferable to put to sea if this can be done in time to avoid the worst of the storm. A tropical storm in a harbour or anchorage is an unpleasant and hazardous experience especially if there are other ships. Even if berthed alongside or if special moorings are used, a ship may be far from secure.

As an example of what is said above, it is common to find ships that were alongside jetties or moored in a harbor pushed ashore or sunk after a hurricane reached their location.

- *Weakening the cyclones*

Cyclones and Hurricanes diminish rather quickly when moving over cooler water that can't supply warm moist tropical air, or over land, again cutting off the source of warm, moist air.

The cyclones can also collapse if they are moving into an area where strong winds high in the atmosphere disperse latent heat, reducing the warm temperatures aloft and raising the surface pressure.

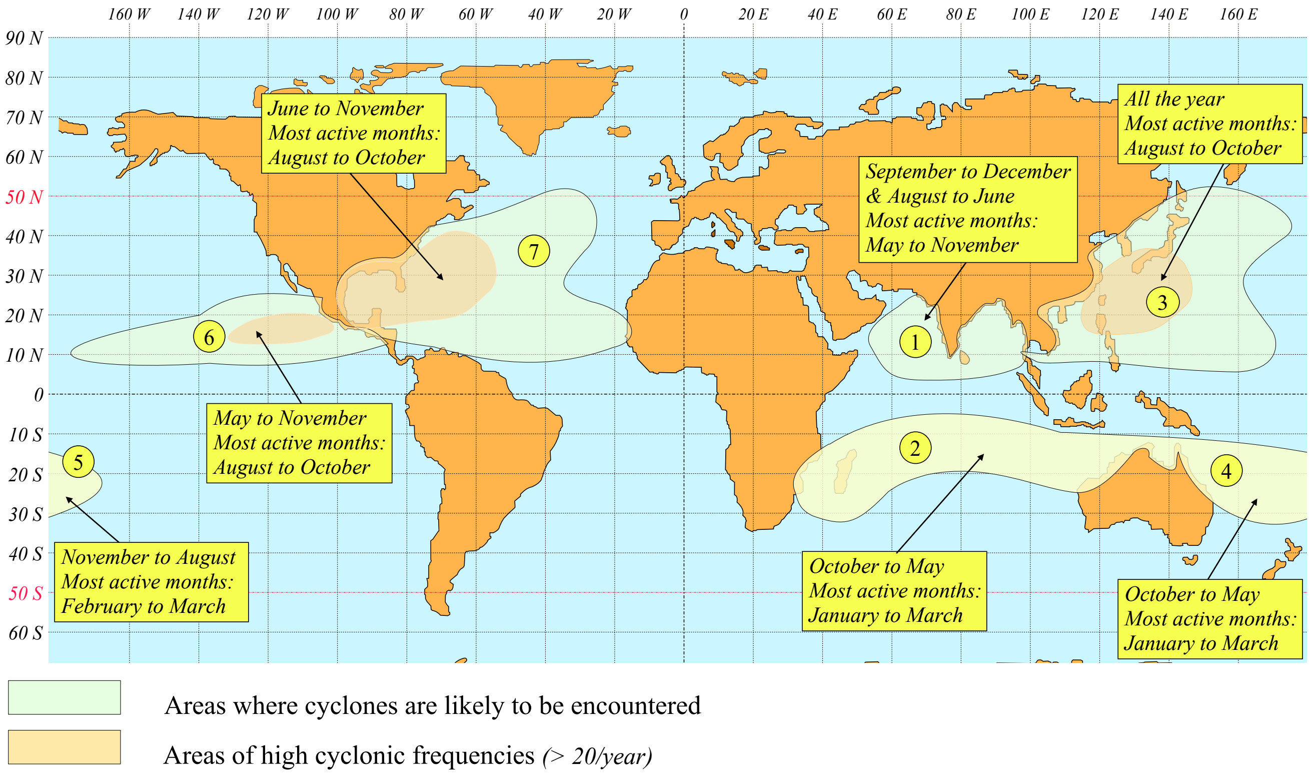
- Main zones where cyclones are likely to happen

A cyclone may develop where all the conditions listed previously can be met.

Areas where Cyclones have favourable conditions to develop are in the Inter-Tropical Convergence Zone. As explained in section 1.2.1, the trade winds from the two hemispheres converge in these zones where cumulonimbus clouds associated with heavy downpours, thunderstorms and squalls are frequently encountered.
There are no cyclones at the equator. For example, there are almost no cyclones in French Guyana, Singapore, or even near the Indian Ocean coast of Africa such as Somalia, Kenya, the northern Tanzania or Zanzibar.
Also, the necessarily warm seas explains why tropical storms are not found in South Atlantic ocean that is under the influence of cold ocean currents. For the same reason, there are no cyclones near the coasts of Chile and Peru, because the "upwelling" phenomenon replaces the warm surface waters of the ocean by wind-driven cold waters from the South Pole and from the very deep depths of the pacific ocean.

In the Northern hemisphere, the summer period is between June and September. However cyclones can develop from June to November.
In the Southern hemisphere, the summer is between December and March, but the cyclonic season extends from November to April or May.

The map and the table below show the main areas where cyclones have been recorded and their average frequency.



Number	Situation	Cyclonic period(s)	Most active period(s)	Number of tropical storms / year	Number of hurricanes / year
1	North of Indian Ocean	September to December & August to June	May and November	5	2
2	Southwest of Indian Ocean	October to May	January to March	10	6
3	Northwest of Pacific Ocean	All year	August to October	24	16
4	Southeast Australia	October to May	January to March	6	8
5	South Pacific	November to August	February to March	8	8
6	Northeast and Central Pacific	May to November	August to October	16	8
7	North Atlantic	June to November	August to October	15	7

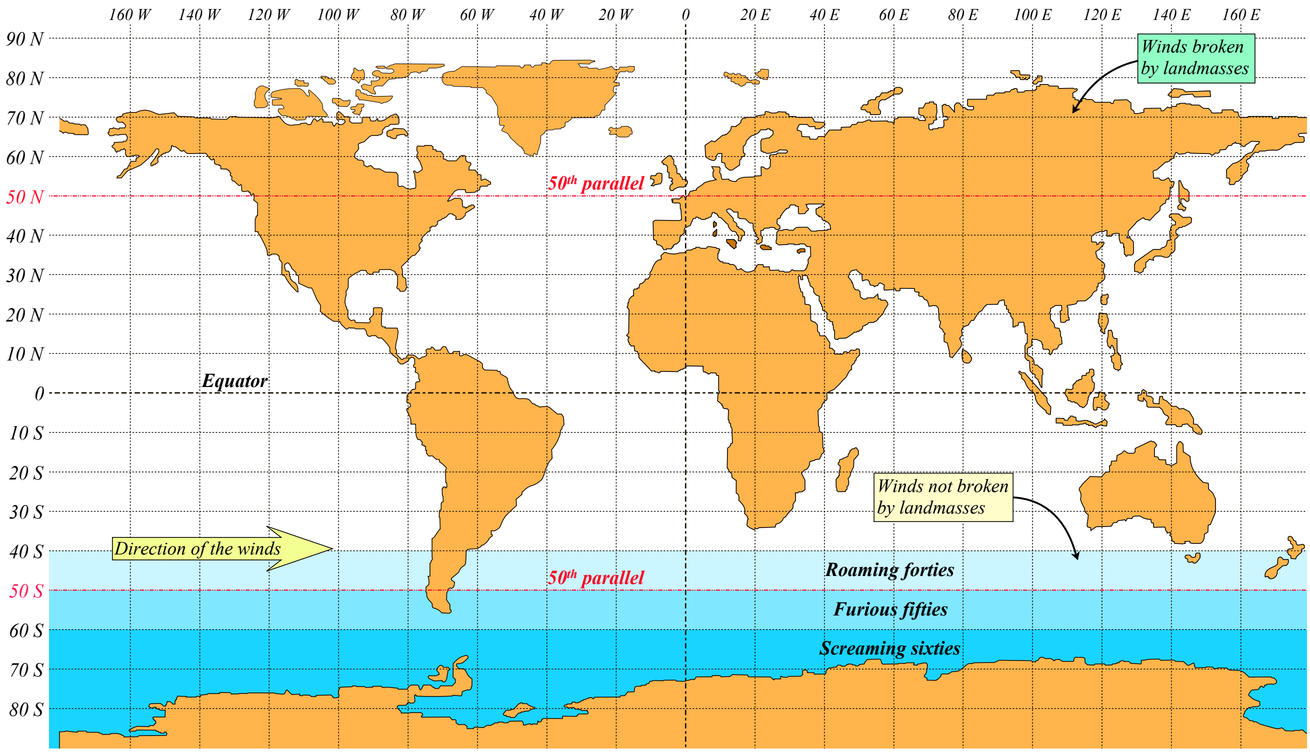
1.3.5 - Polar vortices and their effects

Polar vortices are persistent, large-scale cyclones, circling the North and South poles. The bases of the polar vortices are located in the middle and upper troposphere and extend into the stratosphere. They surround areas of high atmospheric

pressure that are around the poles.
The cold temperatures in the polar regions cause air masses to descend and create high-pressure zones. These air masses of polar origin meet and clash with those of tropical or subtropical origin in convergence zones as the extremely cold and dry air masses do not mix with the warmer moist maritime air masses. Storms with high wind speeds routinely form in these high-temperature gradient regions. The higher the temperature gradient is, the higher the wind speeds will develop. Generally it happens in areas around the 50th parallels of latitude.
Polar vortices are strong in winter and weaken in summer due to their dependence upon the temperature differential between the equator and the poles. The air in a polar vortex circulates counter-clockwise in the Northern hemisphere, and clockwise in the Southern hemisphere.

Polar vortices have an influence on Westerlies that increase in strength when the polar vortices are strong. In the south hemisphere, they are at the origin of the "Roaring Forties", "Furious Fifties"' and "Screaming Sixties".
The "Roaring Forties" are strong westerly winds found between the latitudes of 40 and 50 degrees. These almost continuous winds are powerful as they are not broken by landmasses except for the extremity of the South American continent and New Zealand.
The "Furious Fifties" that are between the latitudes of 50 and 60 degrees and the "Screaming Sixties" that are below 60 degrees latitude are subject to incessant storms and hurricanes with waves that can be over 15 m in height. Icebergs are common in these latitudes.

It must be noticed that some offshore facilities are situated in such areas where the working conditions are much difficult and hazardous.

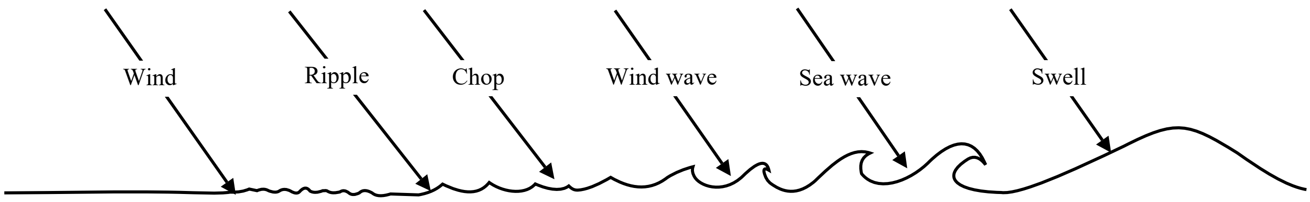


1.4 - Waves and swell

1.4.1 - Waves

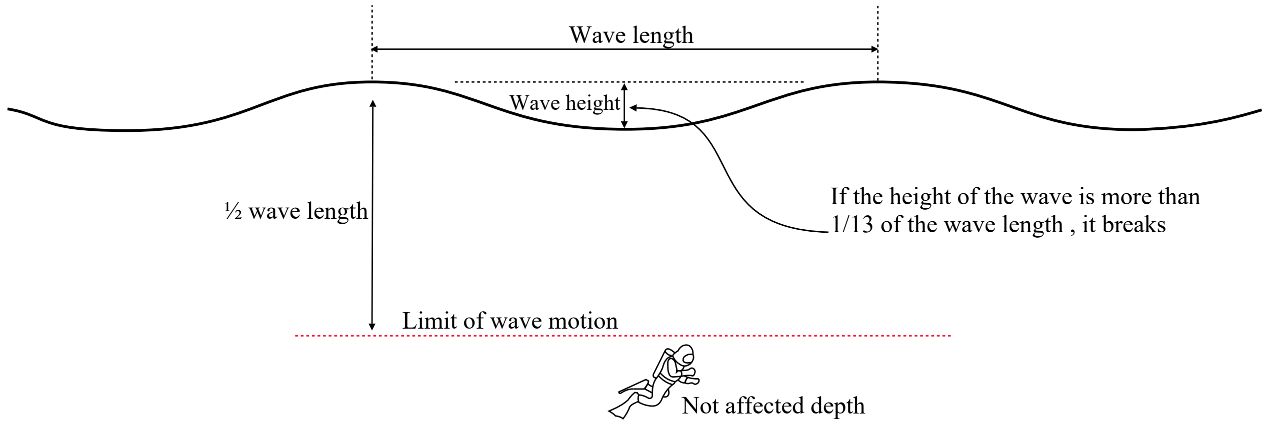
Almost all waves at sea are caused by wind, though some may be caused by other forces of nature such as volcanic explosions, earthquakes or even icebergs calving. The area where waves are formed by wind is known as the generating area, and "sea waves" is the name given to the waves formed in it.

The height of the sea waves depends on how long the wind has been blowing, the fetch, the currents and the wind strength. The Beaufort Wind Scale gives a guide to probable wave heights in the open sea, remote from land, when the wind has been blowing for some time.



Wave generation

The dimensions of a wave are its height, from crest to trough, its wavelength, the distance between crests and the depth to which its movement can be felt. Wavelength is always much greater than height, and if the ratio of height to wavelength becomes greater than about 1:13 the wave breaks. If the wave moves into shallow water, it will slow down, but the wave height increases rapidly. It will start to break when the water depth is equal to about half its wavelength.



The distance that the waves will travel depends on their wavelength. Long wavelengths travel furthest, and it is common to experience a long wavelength swell generated by a wind many miles away.
Under normal conditions, the wave pattern is a combination of one or more wave trains. A local wind, for example, may generate waves on top of a remotely produced swell. The interference between the wave trains can produce considerable variation in wave height.

1.4.2 - Swell

Swell is the wave motion caused by a meteorological disturbance, which persists after the disturbance has died down or moved away.
Swell often travels for considerable distances out of its generating area, maintaining a constant direction as long as it remains in deep water. As the swell travels away from its generating area, its height decreases though its length and speed remain constant, giving rise to the long low regular undulations so characteristic of swell.
The measurement of swell is no easy task. Two or even three swells from different generating areas, are often present and these may be partially obscured by the sea waves also present. For this reason a confused swell is often reported.

Sea state

code	Description	Height in metres
0	Calm - glassy	0
1	Calm - rippled	0.1
2	Smooth wavelets	0.1 - 0.5
3	Slight	0.5 - 1.25
4	Moderate	1.25 - 2.5
5	Rough	2.5 - 4
6	Very rough	4 - 6
7	High	6 - 9
8	Very high	9 - 14
9	Phenomenal	over 14

Swell waves

Swell length	
Description	**Metres**
Short	0 - 100
Average	100 - 200
Long	Over 200
Swell height	
Description	**Metres**
Low	0 - 2
Moderate	2 - 4
Heavy	Over 4

1.4.3 - Rogue waves

Rogue waves also called “extreme storm waves”, are waves which height can be up to 26 m, and perhaps above, and quickly break after their formation. They are very unpredictable and come unexpectedly from directions other than those of prevailing winds and waves. Such waves are responsible for the sinking of several vessels, which some of them were more than 250 m long. When the rogue wave has collapsed, the sea returns to its previous condition.

Because these waves are rare, scientists continue to investigate how and when they form. However, two theories have been emitted:

1. Some scientists think that such waves may result from the addition of different waves that travel at different speeds and have their peaks occasionally overlapping, producing an exceptional mass of water that erects as a wall up to the heights indicated before for several minutes.
2. Another theory is that waves may interact with one another, transferring energy between them. These interactions may result in a similar effect as above.

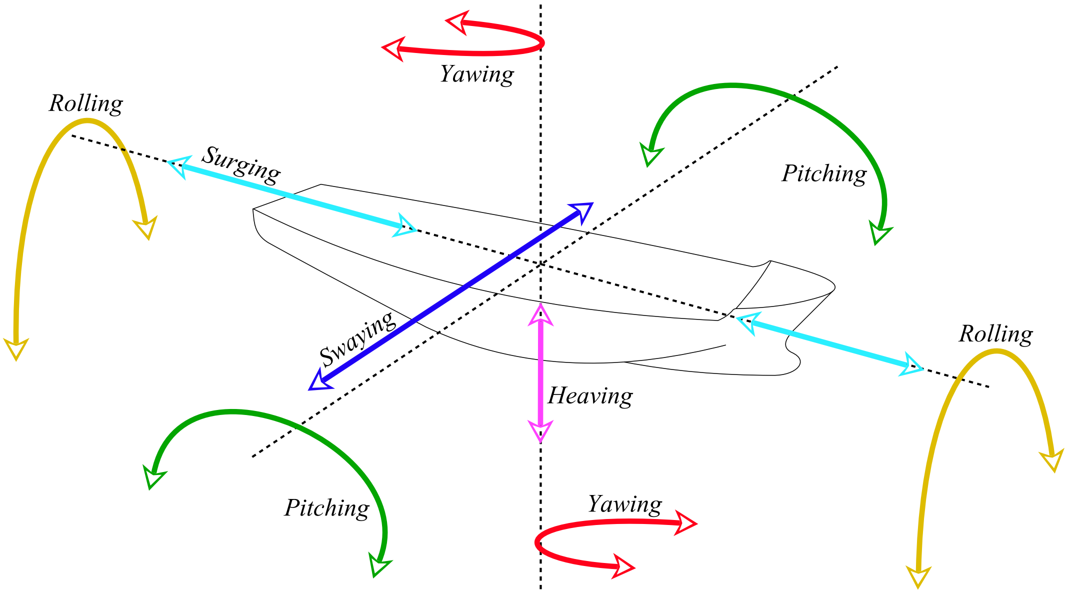
1.5 - Effects of waves and swell

1.5.1 - Effects on the vessel

The weather conditions are likely to exert a combination of forces upon a ship and its cargo over a prolonged period. Such forces may arise from pitching, rolling, heaving, surging, yawing or swaying or a combination of any two or more.
The acceleration values depend on the shapes of the vessel, its beam, the position of the centre of gravity and centre of buoyancy and similar parameters which determine the behavior of ships at sea.

The ship’s movement may be divided into three types of linear motion and three types of rotational motion.

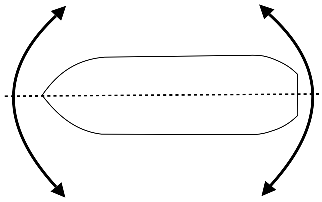
Linear motion	Rotational motion
Surging is motion along the longitudinal axis.	Rolling is motion around the longitudinal axis.
Swaying is motion along the transverse axis.	Pitching is motion around the transverse axis.
Heaving is motion along the vertical axis.	Yawing is motion around the vertical axis.



1.5.1.1 - *Rotational motions*

Yawing:

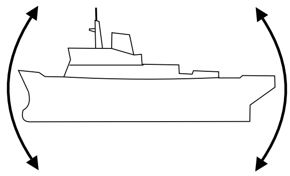
Yawing involves rotation of the ship around its vertical axis. This occurs due to the impossibility of steering a ship on an absolutely straight course. Depending upon sea conditions and rudder deflection, the ship will swing around its projected course. Yawing normally does not happen on a moored barge or 4 point mooring. It has direct effect on a DP vessel heading, but normally, this movement is controlled by the system. Because under control, this movement normally does not affect the diving operation. It also has no effect on the systems installed on deck during the cruising periods.



Pitching:

The ship is lifted at the bow and lowered at the stern and vice versa. Pitching angles vary with the length of the vessel. In relatively long vessels, they are usually less than 5°, but it can be considerably more on small units.

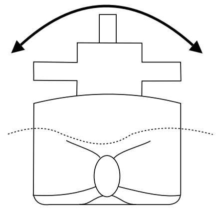
When diving from the stern, which is often the case from supply vessels, these movements create hazardous situations due to the rapid oscillation up and down of the basket/bell, the waves breaking on decks, and the uncontrolled movements during the launching and recovering. In addition the constrains applied to the launch and recovery system can quickly affect its condition.



Rolling:

Rolling involves side-to-side movement of the vessel. The rolling period is defined as the time taken for a full rolling oscillation from the horizontal to the left, back to horizontal then to the right and then back to horizontal. Rolling angle is measured relative to the horizontal. Just in moderate seas, even very large vessels roll to an angle of 10°. In bad weather, angles of 30° are not unusual. Even the largest ships must be expected to roll to such angles. Stabilizers and other anti-heeling systems may help to damp ship movements. However, not all systems are usable or sufficiently effective in bad weather.

A diving operation undertaken from the side of a vessel affected by rolling is very hazardous. Due to the uncontrolled movements, there is a risk of hitting the hull with the baskets/bell during the launching and recovering. The rolling can also create up and down oscillations, initiating shocks and vibrations which can affect the resistance of the whole launch and recovery system in the same manner as the "pitching" effect . Like for the majority of movements applied to the boat, the sea fastenings of the materials stored on deck will be submitted to strong efforts.

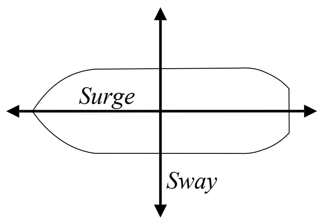


1.5.1.2 - *Linear motions*

Surging and swaying:

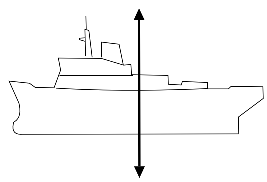
The sea's motion pushes the ship forward and backward and side to side. These movements may occur in all possible axis, not merely, for example, horizontally. If a vessel's fore body is on one side of a wave crest and the after-body is on the other side, the hull may be subjected to considerable torsion forces.

The diving operations undertaken in these conditions are hazardous with the basket/bell banging the hull during the recovering and launching and over-fatigue of the launch and recovery system. On deck, the materials not sufficiently secured can start to move and create additional danger to the personnel.



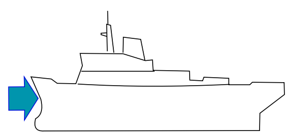
Heaving:

Heaving involves upward and downward acceleration of a ship along its vertical axis. In very long swells, the vessel moves slowly upwards and downwards and is not affected, but the buoyancy varies a lot if the ship is moving through wave crests and troughs with rapid oscillations. Such constant up and down movements have an effect on the materials stored on deck. During the diving operations, they can create hazards due to the basket /bell coming up and down all the time (ears equilibration & possible injuries when coming in and out and hazardous recovery).



Slamming:

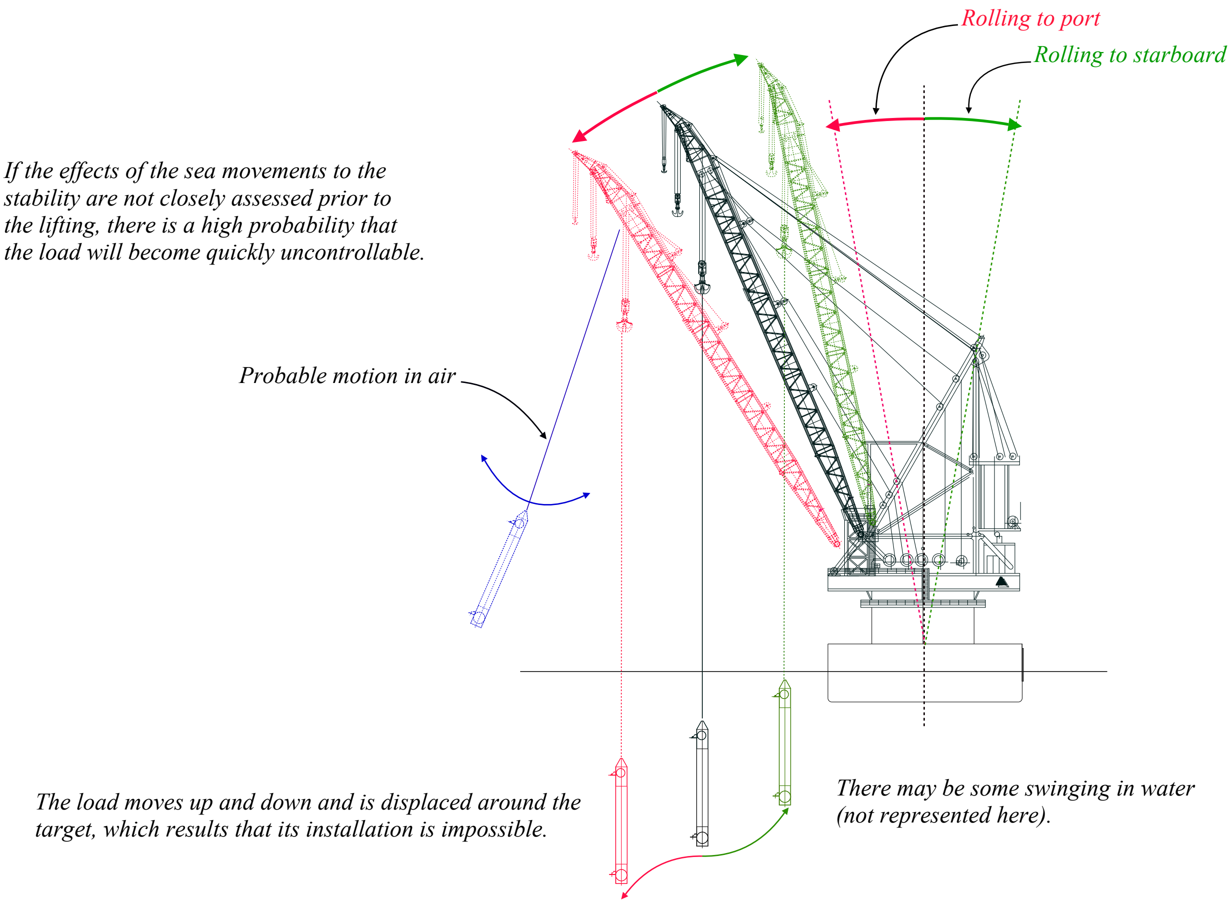
Slamming is not a motion, but the term is used to describe the hydrodynamic impacts which a ship encounters due to the up and down motion of the hull, entry into wave crests and the consequent abrupt immersion of the ship into the sea. This impact creates vibration and stresses to the whole ship and the materials stored in it. Due to their square shapes, barges are very vulnerable to these effects



1.5.2 - Effects on crane operations and systems to control them

1.5.2.1 - Effect on crane operations

In the case of lifting operations by bad sea, the motion of the vessel will be amplified by the boom of the crane, which is often very high. That may result in a load that starts swinging and moving up and down and becomes uncontrollable if the crane and the vessel are not equipped with systems to control these movements.

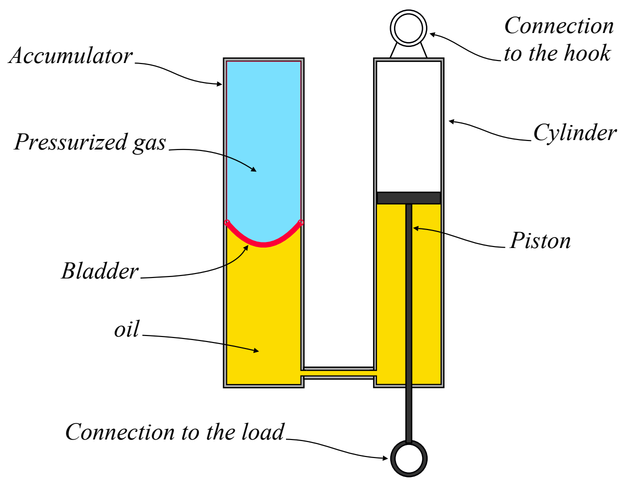


Rolling and pitching effects can be moderated by adjusting the heading of the surface support. However, that can be difficult with anchored vessels due to the constraints resulting from the pre-established anchor positions. Dynamic Positioning vessels offer more possibilities of adjustment, except when they are obliged to work alongside a facility, which is often the case. Also, even though the effects of rolling and pitching can be moderated by adjusting the heading of the vessel, motions such as heaving cannot be under control using such a method. For this reason, modern units are equipped with heave compensation and roll reduction systems.

1.5.2.2 - Heave compensation

Heave Compensation systems are designed to compensate for the vertical vessel movement caused by waves, so the relative distance between the load and seabed or the other vessel is kept constant.
Heave compensation can be divided into two main categories: passive heave compensation (PHC) and active heave compensation (AHC).

Passive Heave Compensation (PHC) requires no input energy to operate. Its principle of work is to accumulate kinetic energy during the vessel movement and then to use this energy to compensate for the change of position between the vessel and the load. Similarly to a shock absorber, it is a reactive device that attempts to isolate the weight from the vessel heave using a compressed gas cushion (usually nitrogen), as shown in the scheme on the side, where the accumulator is charged with pressurized gas set to hold the load at a steady-state on one side of a bladder that separates the gas from the hydraulic oil, which is at the same pressure as the gas and holds the load by pushing on the piston in the cylinder. Note that some systems use a spring in place of the compressed gas.
Passive Heave Compensators are connected between the hook of the crane and the load.

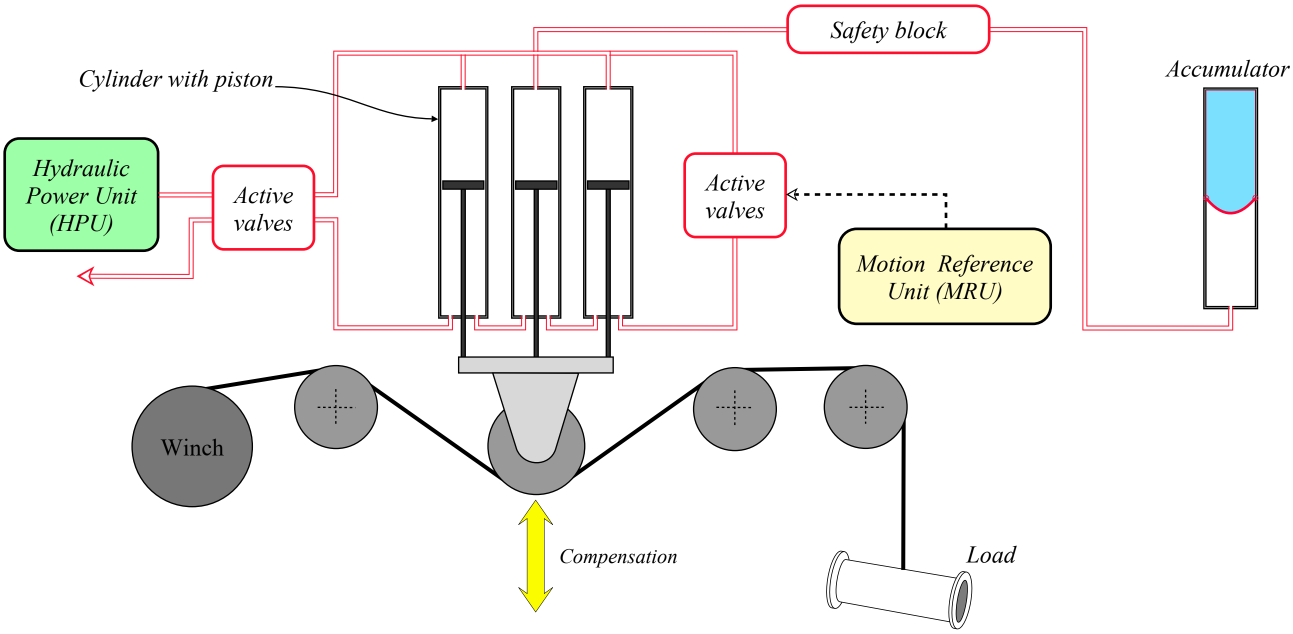


Passive Heave Compensators are often used with lattice boom cranes. Their advantages are that there is no power consumption, they are easy to operate and maintain, and they are relatively cheap.
Their disadvantages are that they require adjustment for the actual load that must have a high resistance to movements, and that they provide a limited range of motion.

Passive Heave Compensation has a limited efficiency, and for this reason, most modern vessels are equipped with Active

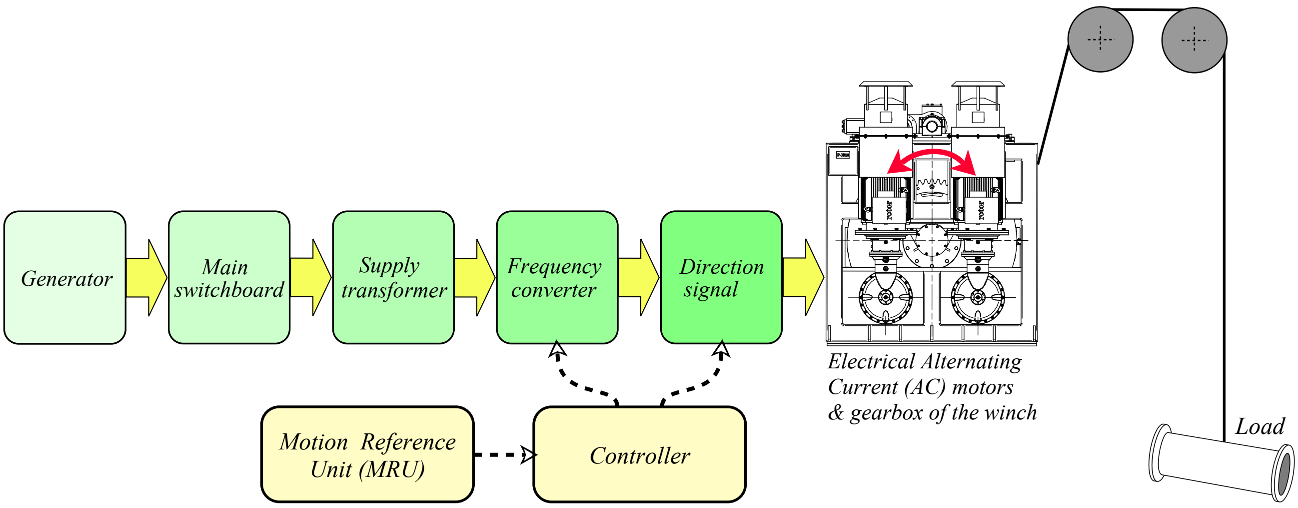
Heave Compensation (AHC) systems.
Active Heave Compensation (AHC) systems utilize a Motion Reference Unit (MRU), which is an inertial measurement unit with multi-axis motion sensors that actively measures all the movements of the vessel. Based on the data collected, a computer calculates the necessary counter motion of the system and controls it in real time. As a result, the length of the cable is permanently adjusted to counteract the vertical movements of the vessel, and there is no variation of the distance of the load from the bottom; thus, its depth is kept constant.
The systems that adjust the length of the cable can be based on hydraulic cylinders, and also rotary hydraulic motors or electric motors that directly move the winch.

Hydraulic cylinder systems are based on pistons that extend and retract according to the direction of the fluid coming from the Hydraulic Power Unit (HPU) through a series of electronically piloted control valves that direct this fluid according to the orders from the Motion Reference Unit (MRU). The cylinders are working independently from the winch, which is usually inactive. They can be installed vertically or horizontally. The function of the accumulator is to maintain a constant pressure in the system.



Rotary hydraulic systems are based on the same principle as hydraulic cylinders. The difference is that the cylinders are replaced by the motor of the winch that acts in one direction or its opposite in function of the direction of the fluid sent from the HPU through the electronically piloted control valves.

Electrically driven heave compensation systems are often used due to their high efficiency as well as the fact that they can be easily fed by the generators of the last generation diesel-electric vessels. Also, it is said that they are more silent than other hydraulic systems. In addition, they do not need an oil reservoir and Hydraulic Power Unit (HPU), which may save some space and attract contractors who do not want to deal with oil replacement and potential leaks.
The advantage of electricity is also that it can act directly to the motor and allows the same torque at a slow speed as that at rapid speed. However, the electricity produced by the generators must be adjusted to the needs of the electric motor of the winch. The scheme below shows an example of a chain of conversion of the electrical current produced by the generator and where the Motion Reference Unit (MRU) intervenes to allow heave compensation.



Definitions:

- *An electric switchboard is a device that directs electricity from one or more sources of supply to several smaller regions of usage. It is an assembly of one or more panels, each of which contains switches that allow electricity* *to be redirected.*

- *A transformer is a device used to change the voltage of an alternating current in one circuit to a different voltage in a second circuit. Transformers consist of a frame-like iron core that has a wire wound around each end. As a current enters the transformer through one of the coils, the magnetic field it produces causes the other coil to pick up the current. If there are more turns on the second coil than on the first coil, the outgoing current will have a higher voltage than the incoming current. This is called a step-up transformer. If there are fewer turns on the second coil than on the first, the outgoing current will have a lower voltage. This is called a step-down transformer.*
- *A frequency converter is a device that converts alternating current (AC) of one frequency to alternating currents of other frequencies. As the speed of an AC motor is dependent on the frequency of the AC power supply changing this frequency allows changing the motor speed. As a result, the rotational speed of the motor can be adjusted using this means instead of using a gearbox, which allows saving energy.*

Active Heave Compensation solves most of the problems that cannot be solved by Passive Heave Compensation, so the distance of the load from the seabed is accurately monitored and stable. That allows increasing the weather window of lifting operations. The major inconveniences of such systems are that they have an elevated demand for power, and the rope wear of cranes equipped with such devices is higher than with classical cranes. Also, they are often complicated, and so are more exposed to breakdowns than passive systems and must be maintained by specialized personnel.

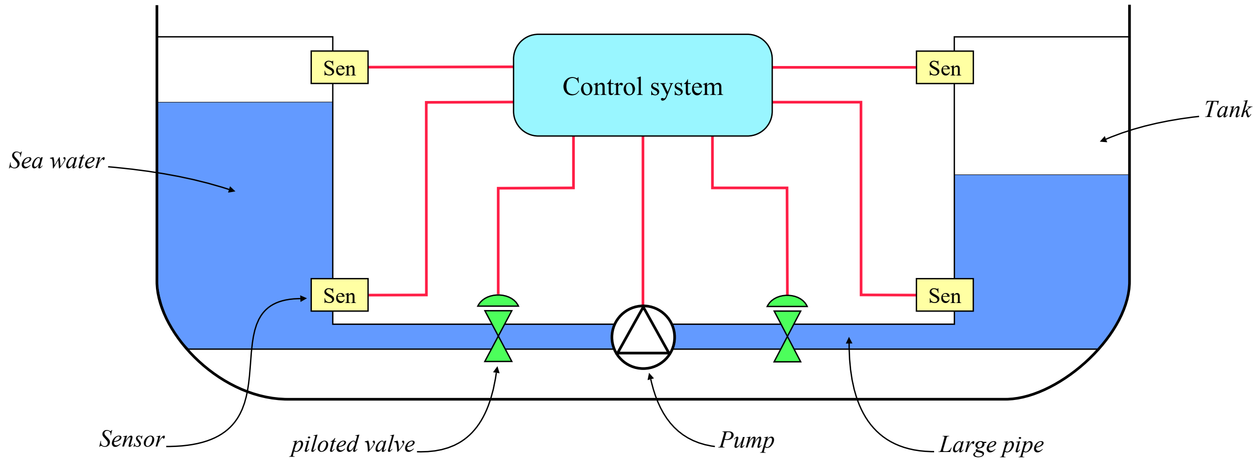
Roll and Pitch compensation:
Active Heave Compensation allows controlling the load vertically on the target but does not control the other movements of the vessel. However, some crane manufacturers have engineered a hydraulically actuated two-directional motion compensation system employing high-speed hydraulic cylinders at the base of the crane.
With the active heave compensation and the two-axis motion compensation system tied into the ship's motion reference unit (a gyro), the system allows full three-axis (x, y, and z) compensation.

1.5.2.3 - Ship stabilization systems

Boats designed for crane operations with heavy loads may have their stability compromised by the cumulated effect of the waves and the weight deployed overboard. Also, heavy and voluminous cargo that may be on deck and unfavourable weather conditions may influence the behaviour of the boat, making her uncomfortable and affecting her safety. For this reason, several systems of stabilization are in place:

- Bilge keels which are plates projecting from the turn of the bilge and extending over the middle half to two-thirds of the ship's length are in place. They create turbulence dampening the motion of the ship and causing a reduction in rolling amplitude. However, they are effective only when the ship is sailing.
- Ballast tanks, which are compartments filled with sea water, are used to provide stability. Also, the water in the ballasts can be pumped out to temporarily reduce the draft of the vessel when required to enter in shallow waters or to maintain the vessel afloat in the case of flooded compartments.
  Note that according to chapter II / rule 8 - "Construction, structure and stability" of SOLAS (International Convention for the Safety of Life at Sea), ballast systems that can be operated during adverse conditions are mandatory with new vessels.
- Anti heeling tanks / anti rolling tanks which can be used as classical ballast tanks are provided to compensate the movements of the cranes. The anti-heeling system automatically detects the angle of the ship and compensates it, which allows the vessels to have continues loading and unloading cargo operation without stopping in between for tilt correction.
  The system consists of ballast tanks which are internally connected to each other by means of pipelines, automatic valves and control systems. When the ship tilts to any of the sides, the heeling sensor sends the signal for a change of ships angle with respect to the ship's upright position to the master control panel. The change of angle is compensated by auto transferring the water from one side to the other side of the ship, maintaining the

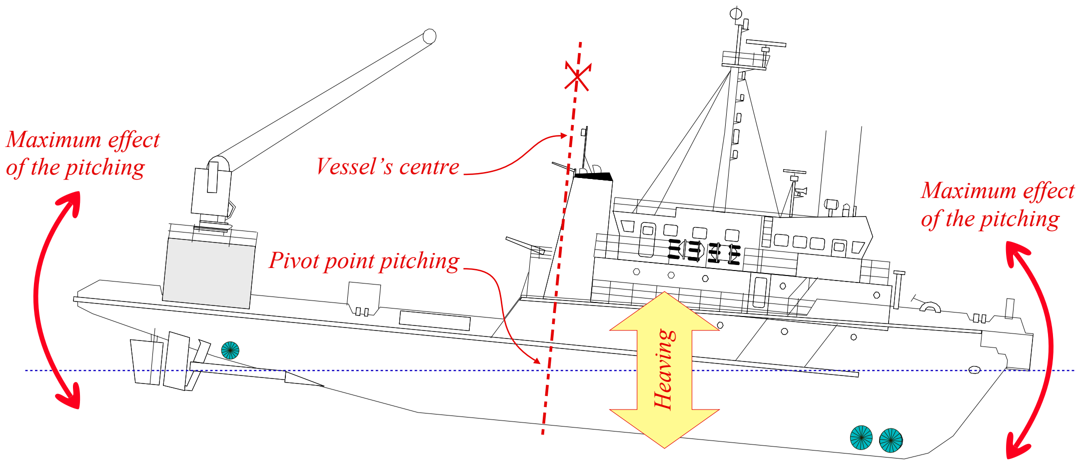
vessel in upright position. The anti heeling system can be used as anti rolling system while the vessel is underway. Similar pumps as those used for ballasting tanks are used to fill and empty these tanks.



1.5.3 - Effects on surface supplied diving operations and the measures to control them

1.5.3.1 - Effect on diving operations

During unfavorable weather conditions, the effects of the movements of the vessel on a basket or a wet bell are similar to those on a load hanged to a crane. Thus, the basket or bell moves up and down and bumps the hull during the launching and recovery, depending on their amplitude. As a result, the launching and recovery can be dangerous for the divers and the personnel operating the system, who can be seriously wounded or ejected to the sea. In addition, the in-water decompression is not performed in optimal conditions, which may result in a decompression illness. Note that in case the deployment of the diver is done from a ladder by such unfavorable weather conditions, the diver can be thrown away by the waves, injured by the up and down movements of the ladder, and not be able to grab it. Also, the movements of the deployment device are amplified if the position of the Launch And Recovery System (LARS) is at the very stern of the vessel, which is frequently the case with diving operations from units tied to platforms.



Another effect is that the elements incorrectly fastened may be torn off from their initial position and become uncontrolled objects acting like battering rams, resulting in injuries or fatalities of the personnel and equipment damages.

1.5.3.2 - Means of control

It must be considered that diving operations from unstable surface support are hazardous and must not be launched. For this reason, the sea condition should be risk assessed, taking into consideration the stability of the surface support used, the exposure of the dive station to the weather, and the available means for the rescue of the divers.
The ship stabilization systems described previously are efficient means of control of the rolling. The use of heave compensation systems similar to those used by cranes is technically possible. Unfortunately, surface-supplied diving systems are usually not provided with such devices, even though they are commonly used with saturation systems. The main reasons are their costs, complexity, and the space necessary to install them. However, several other solutions allow to partially compensate for the problems described above:

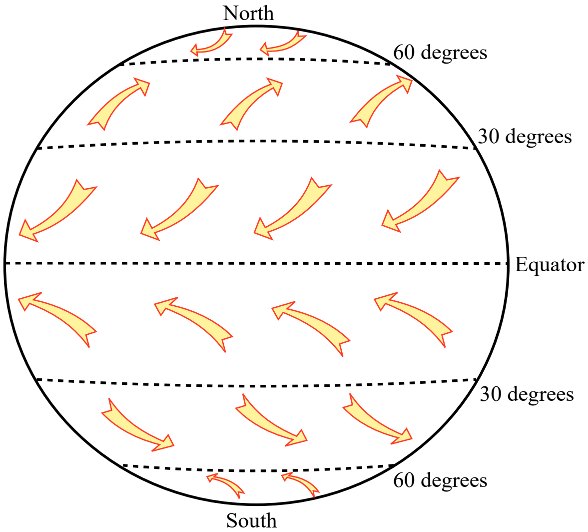
- It is preferable to install the launch and recovery station as close as possible as to the pivot point of the vessel which is not affected by the pitching (see the scheme above).
- A suitable heading of the vessel allows diminishing the rolling and pitching effects. Thus, the ship's position has to be studied during the project preparation. Also, dynamic Positioning vessels can easily modify their orientation, except when working alongside facilities.
- The components of the dive station and tools must be fastened. These fastenings must be calculated and verified.
- Surface decompression procedures must be ready to replace in-water decompression at all times.

1.6 - Ocean currents

The main cause of surface currents in the open ocean is the direct action of the wind on the sea surface and a close correlation accordingly exists between their directions and those of the prevailing winds. It is said that the speed of a wind generated current is usually about 3% of the wind speed. Winds of high constancy blowing over extensive areas of ocean will naturally have a greater effect in producing a current than will variable or local winds. Thus, the Northeast and Southeast Trade Winds of the two hemispheres are the main spring of the mid-latitude surface current circulation.

In the Atlantic and Pacific Oceans, the two Trade Winds drive an immense body of water “W” over a width of some 50° of latitude, broken only by the narrow belt of the E-going Equatorial Counter-current, which is found a few degrees N of the equator in both of these oceans. A similar transport of water to the “W” occurs in the South Indian Ocean driven by the action of the Southeast Trade Wind.

The Trade Winds in both hemispheres are balanced in the higher latitudes by wide belts of variable “W” winds. These produce corresponding belts of predominantly E-going sets in the temperate latitudes of each hemisphere. With these E-going and W-going sets constituting the N and S limbs, there thus arises great continuous circulations of water in each of the major oceans. These cells are centred in about 30°N and S, and extend from about the 10th to at least the 50th parallel in both hemispheres. The direction of the current circulation is clockwise in the N Hemisphere and anti-clockwise in the S Hemisphere.

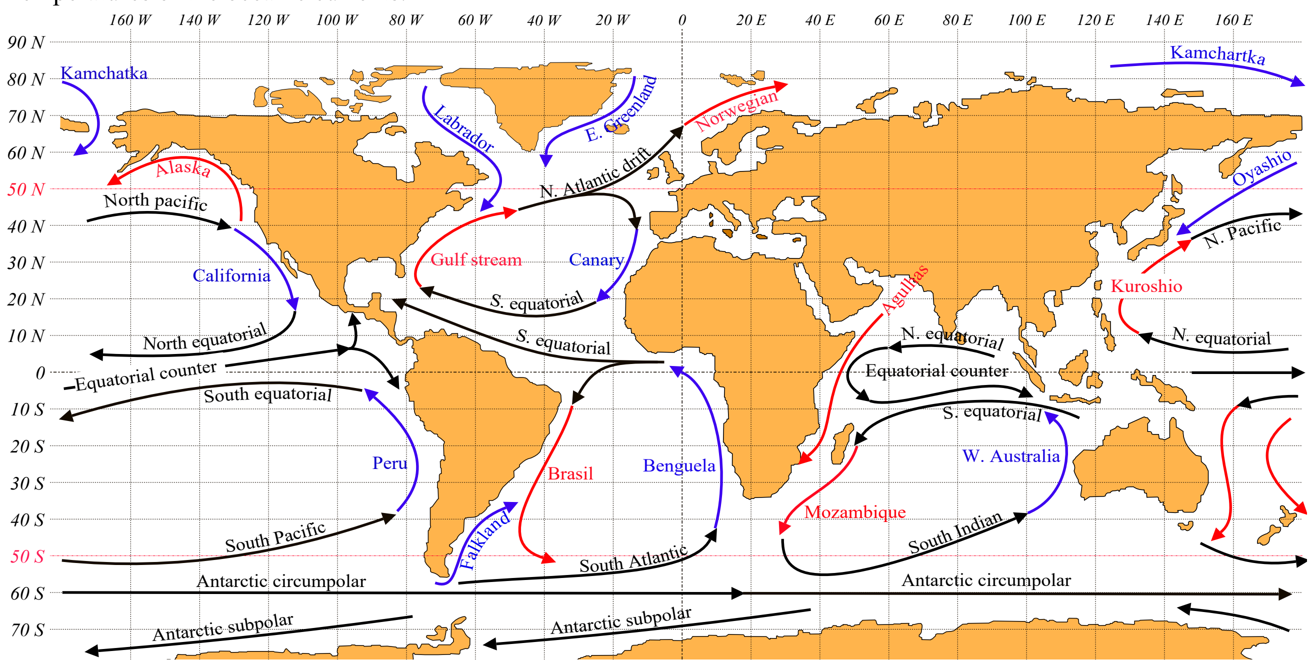


There are also regions of current circulation outside the main gyres, due to various causes, but associated with them or dependent upon them. As an example, part of the North Atlantic Current branches from the main system and flows N of Scotland and N along the coast of Norway. Branching again, part flows past Svalbard into the Arctic Ocean and part enters the Barents Sea.

In the main monsoon regions, the North part of the Indian Ocean, the China Seas and Eastern Archipelago, the current reverses seasonally, flowing in accordance with the monsoon blowing at the time.

The South Atlantic, South Indian and South Pacific Oceans are all open to the Southern Ocean, and the Southern Ocean Current, encircling the globe in an East direction, supplements the South part of the main circulation of each of these three oceans.

Temperatures of the oceanic currents:



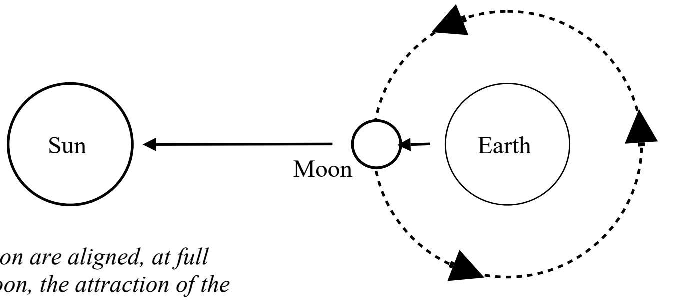
In general, oceanic currents which set continuously E or W acquire temperatures appropriate to the latitude concerned. Currents which set N or S over long distances, however, transport water from higher to lower latitudes, or vice versa. The Gulf Stream, for example, transports water from the Gulf of Mexico to the central part of the North Atlantic Ocean where it gives rise to temperatures well above the latitudinal average. The map on the bottom of the previous page shows the main warm (in red) and cold (in blue) North or South currents, and also the main East or West currents (in black).

1.7 - Tides

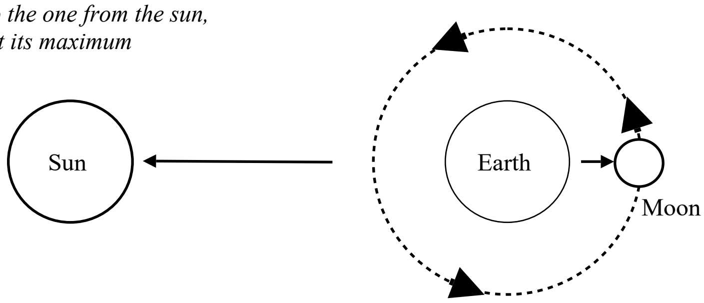
Tides are the rise and fall of sea levels caused by the combined effects of the gravitational forces exerted by the Moon and the Sun and the rotation of the Earth.

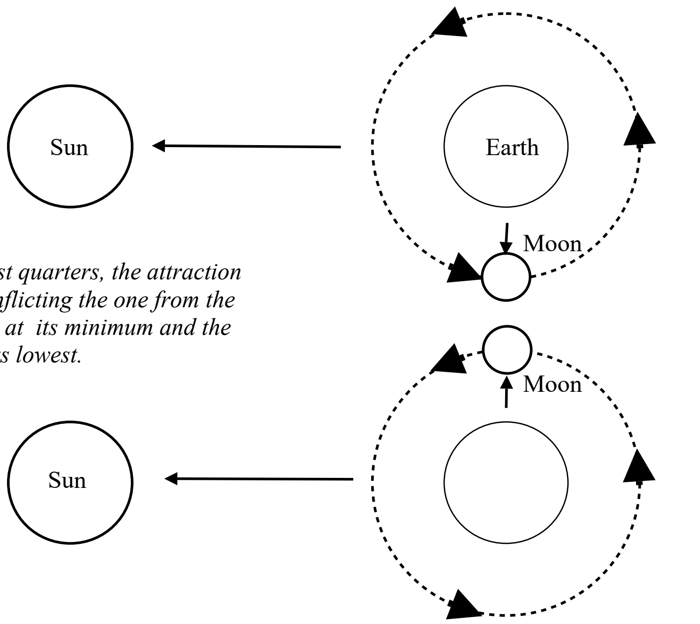
The tidal forces affect the entire earth, but the movement of the solid earth is only centimeters. The atmosphere is much more fluid and compressible, so its surface moves kilometers, in the sense of the contour level of a particular low pressure in the outer atmosphere. Because it is a fluid, the water is also more sensitive to attraction than solid materials and can move up and down several meters, depending of the period of the year.

The peak amplitudes are reached around the spring and autumn equinoxes along the Atlantic coast, or around the summer and winter solstices in some parts of Asia.

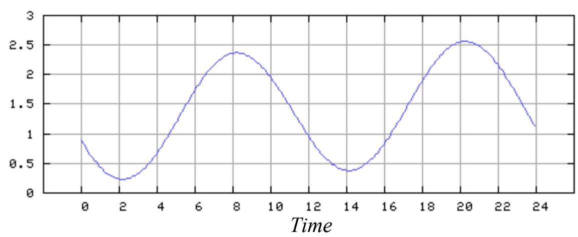


When sun and moon are aligned, at full moon and new moon, the attraction of the moon is adding to the one from the sun, and the effect is at its maximum



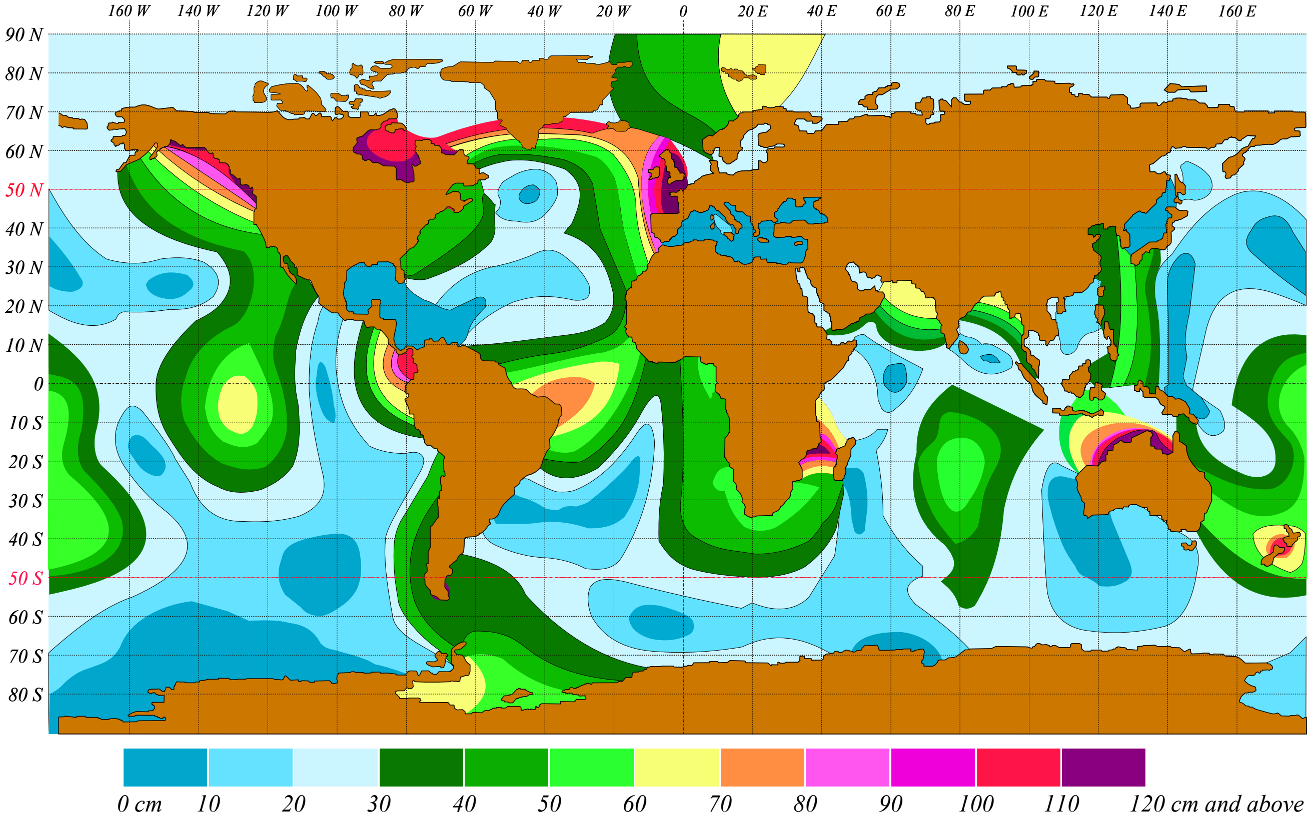


At the first and last quarters, the attraction of the moon is conflicting the one from the sun. The effects is at its minimum and the tidal range is at its lowest.

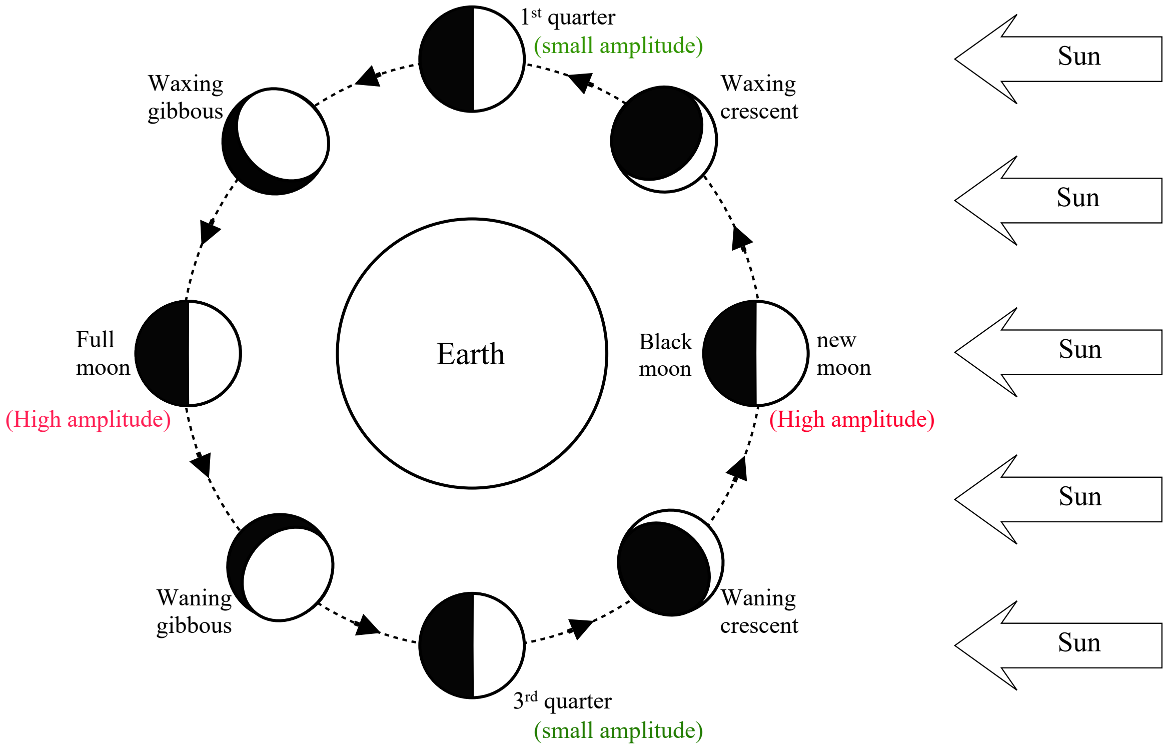


Tides are commonly semi-diurnal (two tidal cycles each day), or diurnal (one tidal cycle per day).
The tidal range is the difference in height between low tide and high tide. It depends on the phase of the moon and the shape of the coastline, so that some bays may have different tidal ranges than the open sea. The times and heights of tides are given in tide tables and can be affected considerably by strong winds.

The map below shows the world tidal amplitudes expressed in centimetres.



The amplitudes of the tides are given on tables, but they can also be evaluated according to the position of the moon :



Tides produce oscillating currents known as tidal streams:
The moment that the tidal current ceases is called “slack water or slack tide”. The tide then reverses direction and is said ‘to be turning”. “Slack water” usually occurs near “high water” and “low water”. But, there are locations where the moments of slack tide differ significantly from those of high and low water.

The amplitude of the tide has a direct effect on the speed and the power of the tidal stream: The bigger the range, the faster the tidal stream. Tidal streams can also increase in speed around headlands and in narrow channels. In some estuaries, the tidal streams can cumulate with the current from the river. These currents are often associated with poor visibility caused by sediment carried by the river. Some tide currents can be as fast as 10 knots.
In addition, due to the interferences initiated by the conditions at the location, the currents may run in different directions at different depths. This possible effect is common and has to be anticipated before launching the dive. Major ocean currents may superimpose on these currents, increasing or decreasing the speed and producing turbulence.

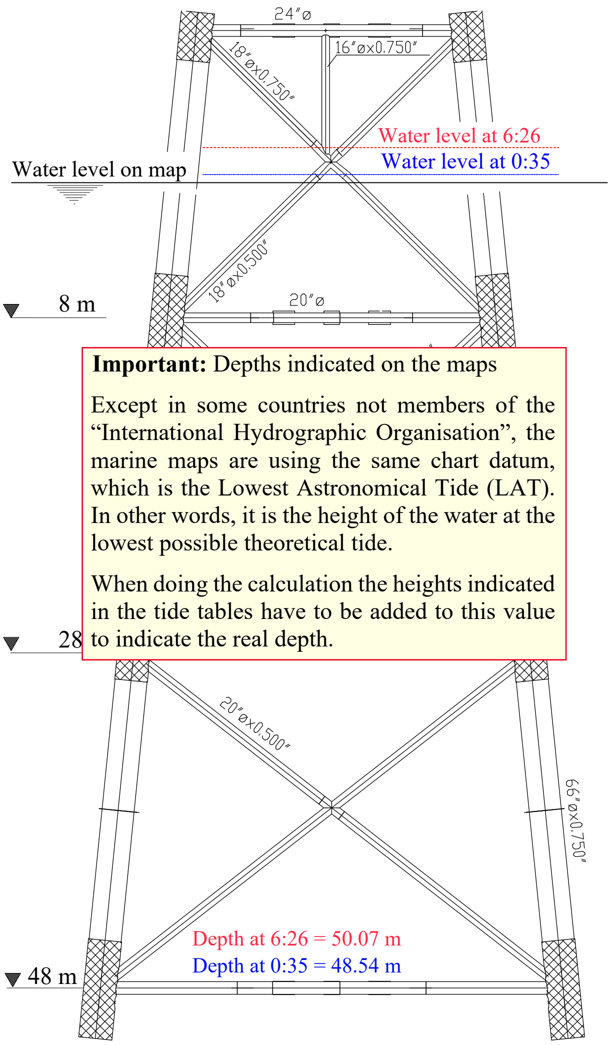
There is “high water” every 12:25 hrs. On average, the tide rises for 6 hours and 12 minutes. This is “the rising, or flood tide”. At the top of the flood, the level remains constant for a short period at “high water slack”. The “falling or ebb tide” then runs for about 6 hours 12 minutes until low water slack. Then the cycle begins again. In some areas, flood and ebb tides may run for considerably less than six hours.
The twelve’s rule is used to calculate the amount of rise or falling. This rule is based on: The range divided by 12 and the duration divided by 6.

Hours	Twelfth of Range
Hour 1	1/12 of range
Hour 2	2/12 of range
Hour 3	3/12 of range
Hour 4	3/12 of range
Hour 5	2/12 of range
Hour 6	1/12 of range

Example: Check the real depth of a platform member indicated at 48 m on the elevation.

The tide table of the day is indicating:

Statement	Time	Height
Low water	0:35	0.4 m
High water	6:26	2.07 m
Low water	12:11	0.45 m
High water	18:30	2.71 m



Important: Depths indicated on the maps

Except in some countries not members of the “International Hydrographic Organisation”, the marine maps are using the same chart datum, which is the Lowest Astronomical Tide (LAT). In other words, it is the height of the water at the lowest possible theoretical tide.

When doing the calculation the heights indicated in the tide tables have to be added to this value to indicate the real depth.

1) Flood tide between 0:35 and 6:28

At 0:35, the depth of the brace will be 48 + 0.4 = 48.4 m

At 6:28, the depth of the brace will be 48 + 2.07 = 50.07 m

The range is 50.07 - 48.4 = 1.67 m

1/12 = 1.67 / 12 = 0.139 m (0.14)
2/12 = 0.139 x 2 = 0.278 m (0.28)
3/12 = 0.139 x 3 = 0.417 m (0.42)

Time	hr	1/12	Height
1:34	1st	1/12	48.4 + 0/139 = 48.54 m
2.32	2nd	2/12	48.539 + 0.278 = 48.81 m
3.31	3rd	3/12	48.81 + 0.417 = 49.23 m
4:29	4th	3/12	49.234 + 0.417 = 49.65 m
5:28	5th	2/12	49.651 + 0.278 = 49.93 m
6:26	6th	1/12	49.929 + 0.139 = 50.07 m

2) Ebb tide between 6:28 and 12:11

At 6:26 the depth of the brace will be 48 + 2.07 = 50.07 m

At 12:11 the depth of the brace will be 48 + 0.44 = 48.45 m

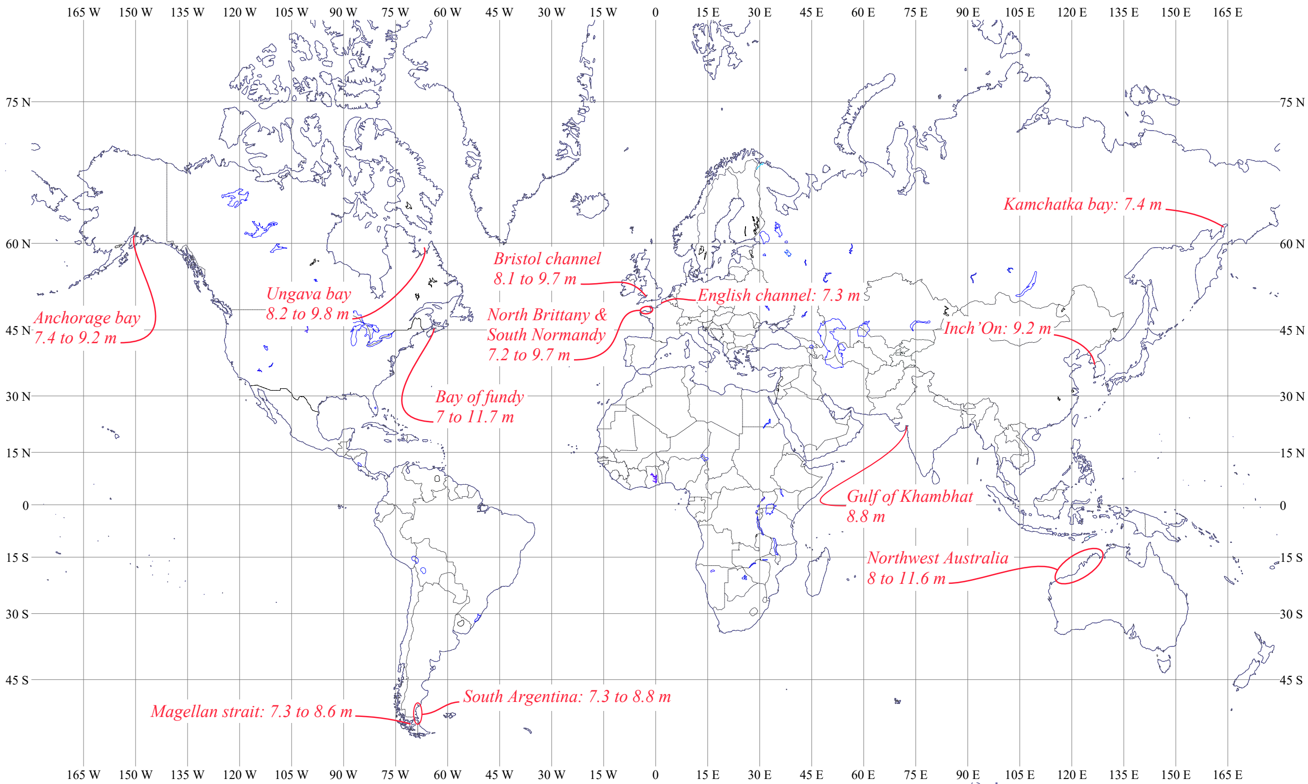
The range is 50.07 - 48.45 = 1.62 m

1/12 = 1.62 / 12 = 0.135 m
2/12 = 0.135 x 2 = 0.27 m
3/12 = 0.135 x 3 = 0.405 m (0.42)

Time	hr	1/12	Height
7:24	1st	1/12	50:07 - 0.135 = 49.93 m
8:21	2nd	2/12	49.935 - 0.27 = 49.66 m
9:18	3rd	3/12	49.665 - 0.405 = 49.26 m
10:15	4th	3/12	49.26 - 0.405 = 48.85 m
11:13	5th	2/12	48.855 - 0.27 = 48.58 m
12:11	6th	1/12	48.785 - 0.135 = 48.45 m

Areas with extreme ranges of tides:
There are a lot of places in the world that have extreme tides such as those indicated in the list below that shows some of the areas where tide ranges are 7 metres and above. These data, that are based on records from the US National Oceanic and Atmosphere Administration (NOAA) and other organizations, do not indicate the exceptional tides.

Location	*Range (metres)*	*Location*	*Range (metres)*
Bay of Fundy - Canada	7 to 11.7 m	South Argentina coast	7.3 to 8.8 m
Northwest Australian coast	8 to 11.6 m	Gulf of Khambhat - India	8.8 m
Ungava bay - Canada	8.2 to 9,8 m	North Brittany and South Normandy coasts - France	7.2 to 9.7 m
Bristol channel - United kingdom	8.1 to 9.7 m	Magellan strait	7.3 to 8.6
Anchorage bay - Alaska - USA	7.4 to 9.2 m	Kamchatka bay Russia (East Siberian coast)	7.4
Inch'On - Korea	9.2 m	English channel, (Cayeux [Fr] & Dover [UK])	7.3 m



There is a belief that says that extreme tides happen in areas above the North and South 45th parallels, which is incorrect, and as it is proved by the map above. Instead, extreme tidal ranges are created by the configurations of the continents and the surrounding coastlines, the prevailing winds, the currents, and other interactions, as indicated in the previous pages. For example, NOAA says that favorable conditions for high ranges of tides in the high latitudes of the northern hemisphere result from the fact that North American, European, and Asian continents are close in these latitudes. Also, a lot of areas where such tidal effects are recorded are bays or locations at the proximity of straits.

High and low tides in Saint Malo - North Brittany - France

1.8 - Effects of underwater currents on divers' performance and safety

As described previously the underwater currents can have several origins which can conflict or cumulate.

- The seasons have direct effect on the power of tidal currents and the ocean currents.
- The weather perturbations can create fast surface currents, most often from surface to 10 m, but sometimes much deeper. These currents can persist for days following the perturbation. Some surface currents can also establish due to bad weather situated far out in the ocean.
- In some estuaries, the rivers are sometimes conflicting with the tides, creating "tidal bore" effects. Tidal bore is due to the incoming tide forming a wave of water that travels above the river. This effect is quite dangerous because these waves are established very suddenly. Most often, there is not a tidal bore, and the river is merely flowing underneath the rising salt water.
- In case of conflicting currents, it is common to have several currents crossing by layers at different depth. It is also frequent to have cold currents establishing through masses of warm water.

All these elements make the predictions of underwater currents difficult.

IMCA D 067 "The effects of underwater currents on divers' performance and safety", that supersedes AODC says:

The effects of currents on divers varies with the individual, the work being done, the diver's position in the water and the diving method used. Currents produce forces which affect not only divers' bodies but also their umbilicals, together with any hoses and cables from the surface to equipment and tools the divers may have at the working depth. Currents can also have an adverse effect on diver deployment devices, for example cages, bells and/or bell umbilicals.

As an increasing amount of energy is devoted to combating the effects of current, as well as carrying out productive operations, it follows that the greater the speed of the current, the shorter will be the period during which the diver will be effective before the onset of significant fatigue.

A diver operating from a bell or wet bell is better able to operate in currents than a surface orientated diver since his umbilical is shorter, is deployed in the horizontal plane, and therefore, attracts much less resistance to water movement. Thus, a diver operating down or upstream from a bell has to contend with the effect of the current on his person only and not on his umbilical.

The force exerted on a diver and his equipment by the current is proportional to the water velocity squared. If the velocity doubles, the force increases four times. The table below shows approximate drag forces exerted on the "average" diver in both a vertical and horizontal position.

Current speed (knots)	*Force on the diver standing facing the current (Max. Profile)*		*Force on the diver horizontal facing the current (min. Profile)*	
	lbs	*Kg force*	*lbs*	*Kg force*
0.5	*6*	*3*	*1*	*0.5*
1	*23*	*10*	*4*	*2*
1.5	*52*	*23*	*9*	*4*
2	*92*	*41*	*15*	*7*
2.5	*144*	*65*	*24*	*11*
3	*207*	*94*	*36*	*16*
3.5	*282*	*128*	*47*	*21*
4	*369*	*167*	*61*	*28*
4.5	*467*	*212*	*78*	*35*
5	*567*	*260*	*96*	*44*

Note: 1 kg force = 9.80 newton (measured at Paris) - 1 pound force = 4.45 newton (measured at London)

The possibility to organize an efficient and safe dive when currents are present depends on factors such as:

A) The physical condition of the diver and his experience with strong currents.
B) Whether the standby diver can be deployed to rescue the diver in the event of an emergency.
C) Whether the work is to be performed in mid-water or on the seabed, and requires strong efforts or not.
D) The means of deployment used (bell or a basket), the umbilical deployed's length, buoyancy, and orientation.
E) The influence of the current on the implementation and the recovery of the equipment to be used.
F) The means of prediction and monitoring that are available to control the underwater current changes.
G) The current's strength and evolution, and if other currents are present at depths above or below.
H) Whether swim-lines, down-lines, means of attachment, and/or an underwater tender are available.
I) Whether the diver can be sheltered by underwater structures or the configuration of the seabed.

Based on the elements above, IMCA has reviewed the previous limitations of AODC 47 for diving operations that may be possible at various current speeds and reduced the exposure of divers to such conditions as displayed below:

	0.0 to 0.7 knots	*0.7 to 1.0 knots*	*1.0 to 1.2 knots*	*1.2 to 1.5 knots*	*1.5 knots and over*
Surface supply in mid water	Normal work	Light work	Special precaution	No diving	No diving
Surface supply on bottom	Normal work	Normal work	Special precaution	No diving	No diving
Bell or wet bell in mid water	Normal work	Light work	Special precaution	No diving	No diving
Bell or wet bell on the bottom	Normal work	Normal work	Special precaution	No diving	No diving

Normal work	*No restrictions*
Light work	*Dives limited to works not requiring strong efforts.*
Special precaution	*Diving in these currents should not be considered a routine operation:* ◦ *Based on the elements indicated previously, the diving supervisor should consult with the divers involved and other people about the feasibility of such an operation.* ◦ *A risk assessment should be performed to ensure that suitable control measures are in place.* ◦ *The team must also consider whether the standby diver can be safely deployed to rescue the diver in the event of an emergency.*
No diving	*Diving operations are normally forbidden beyond 1.2 knots*

The new IMCA limitation of the normal conditions to 1 knot merely follows the limits set up by the industry as a lot of clients have published this maximum limit in their working rules for a very long time.
It is also the rule to ensure that means of prediction *(see in point 5.7 "tides")* and monitoring of the current are in place.
Note that the diving supervisor responsible for the operation is the only person who can order the start of a dive. However, the client representative, the diving superintendent, and the master of the vessel can ask him to abort it if they consider the conditions unsuitable.

1.9 - Water turbidity

1.9.1 Remembering about the visible light in water

Light is an electromagnetic wave oscillation varying in length between 380 and 750 million (manometers). It is apparently white, but through a prism, the white is decomposed into six colours: red, orange, yellow, green, blue and purple. Each of such colours has a wavelength that is specific.

Colour	Min and Max wavelength
Purple	400 - 430 million
Blue	430 - 490 million
Green	490 - 560 million
Yellow	560 - 590 million
Orange	590 - 620 million
Red	620 - 700 million

It is considered that the "hot" colours are those whose wavelength is longer than its 560: yellow, red and orange. Those whose wavelength is shorter are cool colours: blue, green, purple.
The speed of light is 300,000 km/ second. It is the speed at which it enters into the atmosphere and it is not significantly slowed down when it reaches the surface of the sea except during cloudy days.

1.9.1.1 - Reflection of the light

When sunlight reaches the surface of the sea, depending on the angle of incidence, there is a partial reflection back to the atmosphere of a part of the light rays, with the result of a loss of light.
The wider the angle incidence (when the angle of the sun is close to the horizontal of the sea surface), the more reflected rays, therefore, the amount of light that enters the water is small. When the sun is high in the sky, the angle of incidence is smaller (the incident ray will be near the vertical) and, therefore, the loss of light is lower. One can easily deduce that the best time to have underwater natural light are the hours between 11:00 and 15:00 because the sun is at the zenith, and the loss of light by reflection is reduced.

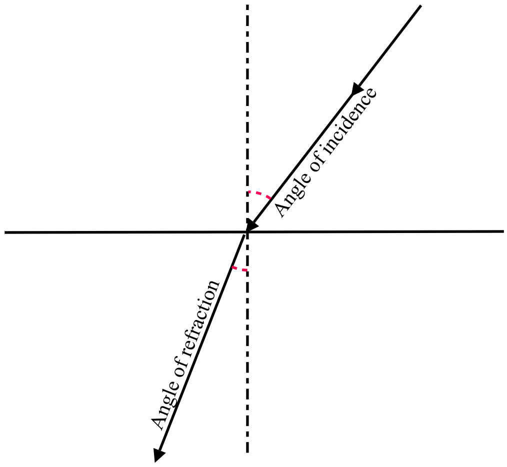
The figures below indicate the loss of light with a clear sky. If the sky is overcast, the light lost in the clouds is about 6% whatever the position of the sun.

Angle of incidence	% of light reflected (lost)
0º	0.02
10º	2.1 %
20º	2.1 %
30º	2.1 %
40º	2.5 %
50º	3.4 %
60º	6 %
70º	13.4 %
80º	38.4 %
90º	100 %

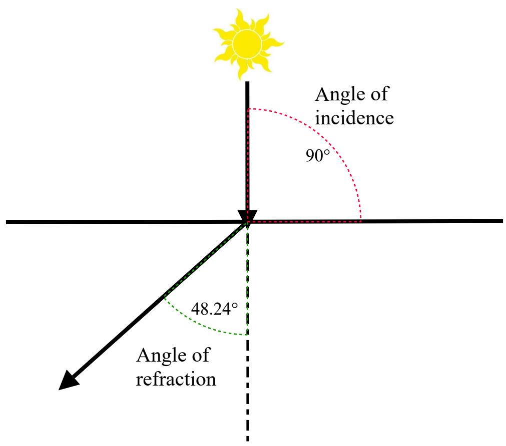
1.9.1.2 - Refraction of the light:

The refraction is the change in direction of a wave due to a change in its transmission medium. The refraction is a constant, and is not really influenced by the weather conditions. For remembering only:

- Refraction law: Sin of the angle of incidence / Sin of the angle of refraction = Constant
- In air: Sin of the angle of incidence / Sin of the angle of refraction = 1 (index of refraction of air)
- In fresh water: Sin of the angle of incidence / Sin of the angle of refraction = 1.33 (index of refraction of fresh water)
- In salt water: Sin of the angle of incidence / Sin of the angle of refraction = 1.34 (index of refraction of salt water)



- Example with an angle of incidence of 90 degrees with sea water:
  - In salt water: Sin of the angle of incidence / Sin of the angle of refraction = 1.34
  - Sin 90° / sin of the angle of refraction
  - Sin 90° = 1   so 1/1.34 = 0.746 = 48.24 degrees



- Effects:
  - 1.333 (index of refraction fresh water) = 4/3
  - An object in the water is seen 1/3 bigger: A fish which appear 1.2 m is in fact 0.8 m long
  - An object appears closer 1/4: an object at 4 m seems to be a 3 m (which often create problems to grab them…)

1.9.2 - Other causes of loss of the light

Other causes of the extinction of light at sea are due to absorption and diffusion in water.

- Absorption
  The water absorbs an amount of light that is proportional to the thickness of the liquid column crossed and the number of particles suspended in it. The first cause is constant, but the second cause varies according to the size, the type and amount of solution.
- Diffuse reflection
  Diffuse reflection is the scattering of light in all directions. There are 2 main causes. The water that normally reflects the light, and the suspended particles composed of mineral salts, sediments, and also varieties of plankton. Because of their irregular shapes, these particles deviate the trajectory of the light, and when crossed by it, they refract it in every direction. This light is then reflected to the particles that were not initially crossed by the initial light, with the same effect. The intensity of the light and the contrast are affected. The well known effect is foggy pictures on the video.
  Because the absorption and diffusion increase with depth, there is a decrease in light intensity which is related to the depth and also a phenomenon of modification of the colours:

Depth	% of sun light
0 m	100 %
1 m	40 %
5 m	25 %
10 m	14 %
20 m	7 %
30 m	3 %
40 m	1.5 %
50 m	0.7 %
60 m	0.25 %
90 m	0.17 %

Depth	Effect on colours
5 m	Red not visible
15 m	Orange not visible
30 m	Yellow not visible
35 m	Blue and green are the most visible
55 m	Purple and indigo are the most visible

The absorption and diffuse reflection are more intense in the vicinity of the coasts and river mouths than open sea due to a greater number of particles in suspension and the direct influence of heavy rains on the rivers and of the bad weather to the shallow sea floors.

That creates situations where the diver is constrained to work in reduced visibility or in the darkness, which creates additional risk, because the hazards are difficult to identify in these conditions. Also, some untrained divers can become anxious in these conditions.

1.10 - precautions

It is the responsibility of employers and their representatives to take care of the health and safety of the people they employ. "Health and Safety at Work etc Act 1974 (1974 c 37)" precise page 3 / point 2 /"general duties":

(1) It shall be the duty of every employer to ensure, so far as is reasonably practicable, the health, safety and welfare at work of all his/her employees.

(2) Without prejudice to the generality of an employer's duty under the preceding subsection, the matters to which that duty extends include in particular….(e) the provision and maintenance of a working environment for his employees that is, so far as is reasonably practicable, safe, without risks to health, and adequate as regards facilities and arrangements for their welfare at work.

Managing the weather conditions is one of the major problems during diving operations, and the diving supervisors and superintendent need to organise all the necessary precautions to monitor closely the weather and recover the divers safely any time.

It must be remembered that IMCA 14 says point 3.5 that the supervisor is the only person who can launch a dive. IMCA 14 indicates also point 3.5 that the supervisor has authority to give orders in relation to Health and Safety to any person taking part or who has any influence over the diving operation…

To launch a bell diving operation, depending on the surface support and its positioning, the following guidelines should be kept in mind:

- Diving operations from an unstable surface support are hazardous and must not be launched.
- The sea condition a closed bell can be launched should be risk assessed, taking into consideration the stability of the surface support used, the exposition of the dive station to the weather, and the procedure selected for the rescue of the diving bell.

The dive can be launched only if the supervisor is 100% sure that the bell and the means of rescue selected (divers or ROV) can be launched, and recovered safely. The dive should be stopped if it appears that the means for the rescue of the bell cannot be launched safely.

For example:

- If the means of rescue planned is surface supplied divers using baskets, the maximum sea condition on the Beaufort scale should be those applicable for the launching of the surface supplied diving operation (between force 4 and 5 with a maximum of 1.5 m wave height under the diving station), despite the fact that a closed bell can be launched in the roughest conditions.
- If the vessel is a powerful dynamic positioning equipped with 2 heave compensated bells coming down from the middle of the ship, and with a dive station enclosed inside the vessel, the maximum sea condition can be according to what the ensemble vessel - bell can withstand.

- The underwater current speed must be as indicated in point 5.8, and the conditions should be suitable for the means of rescue selected.
- The divers must also be trained to work and orientate in reduced underwater visibility, or better in the complete darkness in case of water with high turbidity.

Other precautions:

Some accidents not linked to diving, but to vessels caught in storms despite weather forecast alerts, have happened.
Some of these accidents were the result of decisions of the onboard teams to follow instructions coming from their company offices onshore. That is why the points indicated below must be remembered by the people on board the vessel:

- Despite the huge progress resulting from modern means of observation and analysis, the weather forecast remains only prediction, and the situation on the site could be different (worse). It is the duty of the people on board to observe the evolution of the weather and take appropriate action regarding the safety of the people and the materials they are in charge of.
- It is the duty of the diving supervisors and diving superintendents to warn the people in charge, of the dangers their vessel may face if they consider that the safety of the vessel and the onboard personnel may be jeopardized.
- It is the duty of the vessel master to ensure that all the precautions are in place to be able to withstand safely the planned weather conditions and to leave an area without damage if the weather conditions get worse than initially planned. These precautions include the capacity to recover the anchors of the vessel safely.

2 - Communications

The Diving Supervisor must have reliable communications with everyone involved in the operation and needs access to all of the communications of the vessel or installation. Communications include all available systems, word of mouth, documentation, radio, telephone, fax , E mail, etc…

Video is also a type of communication system, letting people see what is happening. It has also been used to transmit hand signals or written messages when audio communication has failed.

The Diving Supervisor is directly responsible for communications with the diver. He must have voice communication and be able to monitor the diver's breathing pattern at all times. He must not hand over communication to any other person except another properly appointed and qualified Diving Supervisor.

When an ROV is in use, the Diving Supervisor has overall responsibility for the safety of the whole operation. Close communication with the ROV supervisor is vital. There should be a dedicated communications link and a repeat video monitor showing the same picture seen by the ROV pilot.

2.1 - Verbal communications

2.1.1 - Language

Most teams working in the offshore industry are multinational diving teams where English is the language for communications. Still, it may happen that some divers do not speak fluent English and that the language they use is their national language. In this case:

- The language used must be common to all the members of the team.
- The supervisor and some members of the team must also speak fluent English to communicate to other teams.
- The communications between the supervisor and the divers must be direct communications. The use of translators create the risk of messages being misinterpreted and should be banished.

2.1.2 - Voice communication through radio and on deck

Voice communication is used to pass clear, complete and accurate information in plain language.
Since English is the internationally accepted language, voice procedure and phonetic codes are based in English to communicate with external teams and inside the team when English is the common language. The following words and phrases are used in radio voice communication:

Word	*Translation*
Acknowledge	*I understand your message.*
Affirmative	*Yes, or you are clear to proceed.*
All stop	*Stop the action and wait for further instructions.*
Come up or down	*Lift or lower, on a winch or crane.*
Correction	*An alteration to the previous message.*
Easy	*Lift or lower slowly on a winch or crane. "Slowly" is also used*
Go ahead	*Proceed with your message.*
How do you read?	*How are you receiving me?*
I say again	*Repetition of a message.*
Negative	*No, or you are not clear to proceed*
Over	*Message ended and waiting for a reply*
Out	*Message ended and no reply expected*
Read back	*Repeat the message as received*
Repeat	*Similar to "say again" but usually used to emphasise a word or phrase*
Roger	*I have received all of your last transmission.*
Say again	*Repeat your message*
Say again from..	*Repeat your message from..*
Slowly	*Lift or lower slowly on a winch or crane. "Easy" is also used*
Speak slower	*Self explanatory*
Standby	*Wait for another message*
That is correct	*Self explanatory*
Verify	*Confirm the accuracy of your last message*
Wilco	*I have understood your message and will carry out the instructions.*

As indicated before, the national language may be used inside some teams, and in this case, the procedures used in English must be adapted.

- Written aide-memoire must be used.
- Voice communications have to be reduced to the minimum.
- Voice communication must be slow and clear.
- IMCA D 022 recommends not using ambiguous words like ‘may’, ‘might’, ‘should’, ‘could’ , or ‘can’, but use more directive words.
- Standard words and phrases to be used.
- The recipient of the messages must be able to repeat all instructions back.
- Let the other person know when you've finished speaking, usually by saying "over".
- There must be a procedure to deal with communications breakdown. Back up and alternative methods of communication must be in place before starting the job.

For spelling out words, it is preferable to use the phonetic alphabet. It is intended for unambiguous international use, as is the pronunciation of the numbers. If there is any difficulty in remembering the phonetic alphabet, other suitable words can be used.

Letter / number	Pronounce		Letter / number	Pronounce
A	Alpha		Q	Quebec
B	Bravo		R	Romeo
C	Charlie		S	Sierra
D	Delta		T	Tango
E	Echo		U	Uniform
F	Fox-trot		V	Victor
G	Gulf		W	Whisky
H	Hotel		X	X ray
I	India		Y	Yankee
J	Juliet		Z	Zulu
K	Kilo		0	Zero
L	Lima		1	Wun
M	Mike		2	Too
N	November		5	Fiver
O	Oscar		6	Sixter
P	Papa		7	Sev-en

2.1.3 - Voice Communication with the Diver

a) Communication during the working phases

- There must be two-way voice communication with the diver at all times. Voice communications are made more difficult by the noise of the diver’s breathing and other noises such as water jetting, burning, hydraulic tools etc.
- Communications from the surface should, as far as possible, be fitted around these noises. It is time-wasting and tiring to try and talk over a loud noise.
- If there is an urgent need to talk to the diver, most underwater tools and equipment must be switched off at the surface to reduce noise, provided there is no hazard to the diver.
- Talking to the diver during lifts, lowers, or other operations where he may need to warn the surface urgently of any problems has to be avoided.
- The tasks must be planned so that they involve the minimum amount of voice communication.
- The names for the tools, equipment, locations, and procedures that will be involved must be agreed before starting the dive. Two or three syllable names are clearer than single syllable names.
- The messages must be short and simple. The diver may have to turn off his free flow or stop breathing to listen.
- The diver and supervisor must be aware of the time lag in the chain of communication. An instruction from the diver may take 30 seconds or more to reach the crane diver via the Diving Supervisor, and more time before the instruction is acted upon.
- All voice communications, starting with the pre-dive checks must be recorded. The recording must be kept until it is clear that there have been no problems during or following the dive. It is recommended that recordings are kept for at least 24 hours. If an incident or accident occurs, the tape must be kept in a safe place for the investigation.

- Rope and hand signals may be used routinely for tender to diver and diver to diver. Different signals may be used by divers trained in different countries so on a multinational crew signals must be standardised.

b) Communications when using heliox

Note that such communications are also described in the document "Description of a saturation system"

When breathing Heliox mixes, divers' speech are very high-pitched and hard to understand to people not used to it. The distortion is a result of two changes in environment:

1) The speed of sound, and thus the resonance frequencies change with the gas mixture. For example, at depths of 300 meters or more, the heliox mixture contains so much helium that the speed of sound in the mixture is about the same as the speed in pure helium, which is 2.9 times the speed in air.
2) The change of pressure adds a stiffness to the throat and mouth and gives the first resonance an additional upward shift. Notice that at high frequencies the pressure has no noticeable influence.

The total effect from these two changes in the environment is a strong non-linear compression of the resonance. The pitch (the fundamental frequency generated by the vocal cords), however, is kept almost constant.

To solve the problems of distortion due to the use of helium, means for processing of speech (unscrambling) should be available. These requirements should apply to verbal communication from diver's helmets, bells, chambers.

The models can be divided into two groups, depending on their processing algorithm:

- Time domain
- Frequency domain

During the 80's and 90's, most of the commercial unscramblers were based on "time domain", and some materials from this period are still in use. Materials only based on time domain algorithm are much dependent on speech quality: Helmet free flow noise, poor quality microphones and badly distorted voices (due to oral/nasal-mask shunting) are some of the problems that impair the function (the pitch detection) and speech restoration in this type of unscramble.

New models which are based on the association of the 2 principles, or only on full frequency domain solutions are now available on the market and have greatly improved communications.

The communication system for divers in both water and hyperbaric chambers should be tested for intelligibility under as realistic operational conditions as possible.

NORSOK standard U-100 edition 4 recommends a 'modified rhyme test' (MRT) to be used to verify that the operational communications systems are in accordance with the requirements for speech intelligibility in the table below:

Communication requirements	Score
Exceptionally high intelligibility; separate syllables understood.	97 %
Normally acceptable in intelligibility; about 98 % of sentences correctly heard; single digits understood.	91 %
Minimally acceptable intelligibility; limited standardized phrases understood; about 90 % sentences correctly heard (not acceptable for operational equipment)	75 %

c) Loss of communication

- In case of loss of voice communication, the surface should:
  - Contact the diver using line signals, or by flashing the diver's light, or if using a tool linked to surface, stopping the tool, or if it is on site, use the ROV lights.
  - The diver can reply by line signals or by hand signals to a video camera. He should return to the bell.
  - If contact cannot be established, or there is any doubt about the diver's condition, the standby diver should be sent in immediately.
- If the diver receives no answer to his/her voice message:

Signal	Tender to diver	Diver to tender
Succession of pulls	Stand-by diver on his way	Emergency! I need assistance
4 pulls	Go back to the bell	I am going back to the bell. Or: Pull me up
3 pulls	Go down	I am going down. Or: Give me some slack
2 pulls	Come up	Come up on my umbilical
1 pull	Stop	Stop

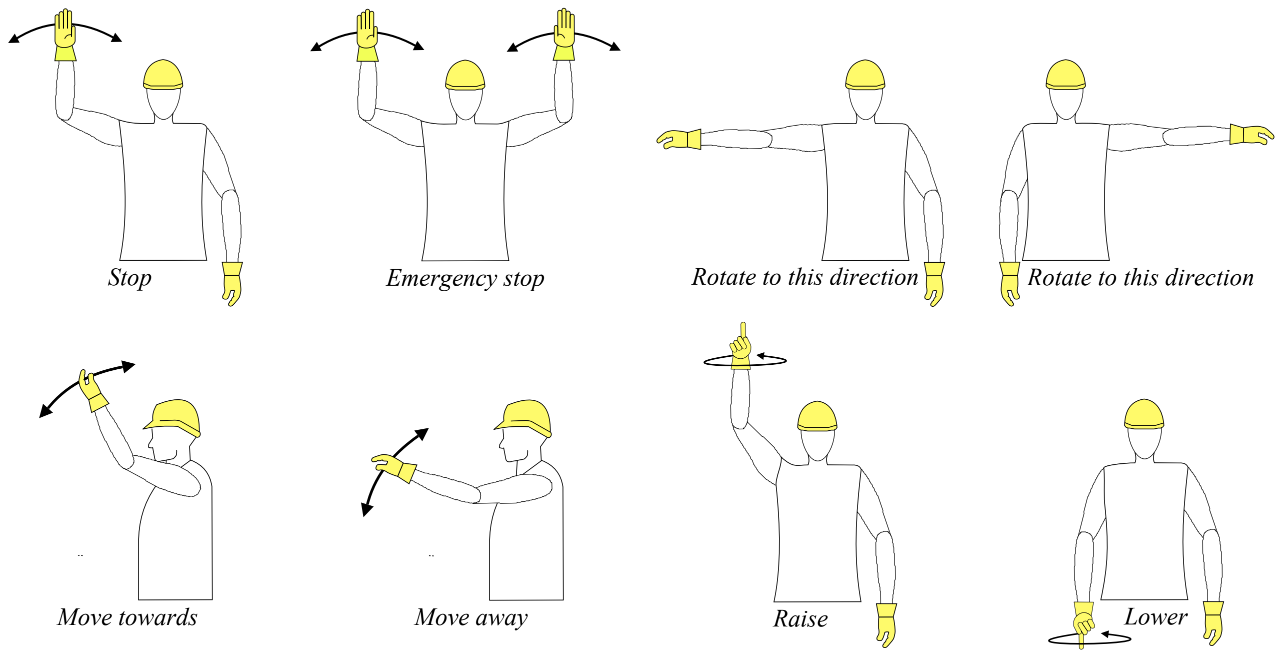
d) Loss of communication of the bell(tapping code):

In case of a lost bell, and the communications through the umbilical are impossible, through water communications should be deployed to restore the contact with the divers in the bell. If the though water communications are not working, the Tapping code IMO/IMCA/OGP should be used:

Tapping code	Situation
3.3	Communication opening procedure (inside and outside)
1	Yes or affirmative or agreed
3	No or negative or disagreed
2.2	Repeat please
2	Stop
5	Have you got a seal?
6	Stand by to be pulled up
1.2.1.2	Get ready for through water transfer (open your hatch)
2.3.2.3	You will NOT release your ballasts
4.4	Do release your ballast in 30 minutes from now
1.2.3	Do increase your pressure
3.3	Communication closing procedure (inside and outside)

2.2 - Hand signal communications

Hand signals are frequently used to control lifting operations using winches and cranes.
Under normal circumstances, the direction of the crane on deck is the responsibility of the banks-man/slinger, but on small units, it may be done by experienced divers.
The signals given below are those generally employed everywhere. Nevertheless, many other codes may be used by organizations that should be confirmed by the team involved before starting the operation. Also, note that since there are portable radios that can be integrated into the helmet of the banks-man, the crane operator must be directed using such devices. Thus, hand signal communications should be used only to confirm what is said by radio.



Regarding the responsibilities, IMCA SEL 019/ M 187 says the following:

- *The lift supervisor, who should be nominated by the competent person, is defined as the person who is charged with actively supervising the lifting operation on site. This could be a deck officer, diving superintendent, competent person, deck foreman, banksman/slinger, shift supervisor or similar.*
- *Supervision should be proportionate to the exposure to risk created by the lifting operation and the experience and capabilities of the personnel involved in individual lifting operations.*

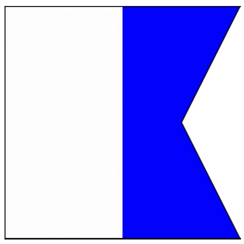
2.3 - Flag and lights communications

Flags are used in maritime communication to indicate a status, a need or an intention of action. These flags correspond to the letter of alphabet. Each flag has a meaning and can be used also in combination to compose a message.

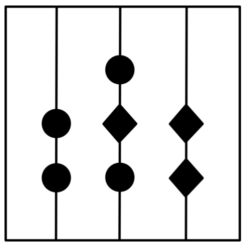
Meanings of flags used individually		
Alpha: *Diver in the water*	Juliet (1): *Fire on board*	Quebec: *My vessel is healthy and I request to enter in port.*
Bravo: *I have a dangerous cargo*	Juliet (2): *Leaking dangerous cargo*	Romeo: —
Charlie: *affirmative*	Kilo: *I wish to communicate*	Sierra: *I am operating astern propulsion*
Delta: *Keep clear of me*	Lima (at sea): *Stop your vessel (order)*	Tango: *Keep clear of me*
Echo: I alter my course to Starboard	Lima (in harbor): *Ship quarantined*	Uniform: *You are running into danger*
Foxtrot: *I am disabled - contact me*	Mike: *I am stopped*	Victor: *I require assistance*
Golf: *Pilot asked*	November: *Negative*	X-ray: *Stop you intention*
Hotel: *Pilot on board*	Oscar: *Man overboard*	Yankee: *I am dragging anchor*
India: *I alter my course to port*	Papa: *Vessel ready to sail*	Zulu: *I require a tug*

Flags and lights used during diving operations:

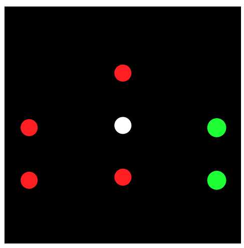
<u>The flag that must be on the mast of the boat to indicate diving operation is the alpha flag</u>. Before starting the diving activities, the team must ensure that the Alpha flag is installed and visible from any direction. This flag will have to be removed after the diving operations.



<u>In addition to the Alpha flag</u> the working signals for a vessel undertaking underwater operations during daylight, which is Ball - Diamond - Ball, must be displayed . The 2 balls indicate the obstructed side, diamonds indicate clear side.



During the night the vessel must indicate the diving operations using light signals. The main signal is Red - White - Red . The red lights indicate the obstructed side, green lights indicate clear side.



2.4 - Audible alarms

Particular elements such as Dynamic Positioning system light status are fitted with audible alarms associated to a light colour (yellow or red). The bridge also uses audible alarms to inform the teams of onboard emergencies, and these codes must be remembered by the divers (particularly the young divers) during the tool box talks:

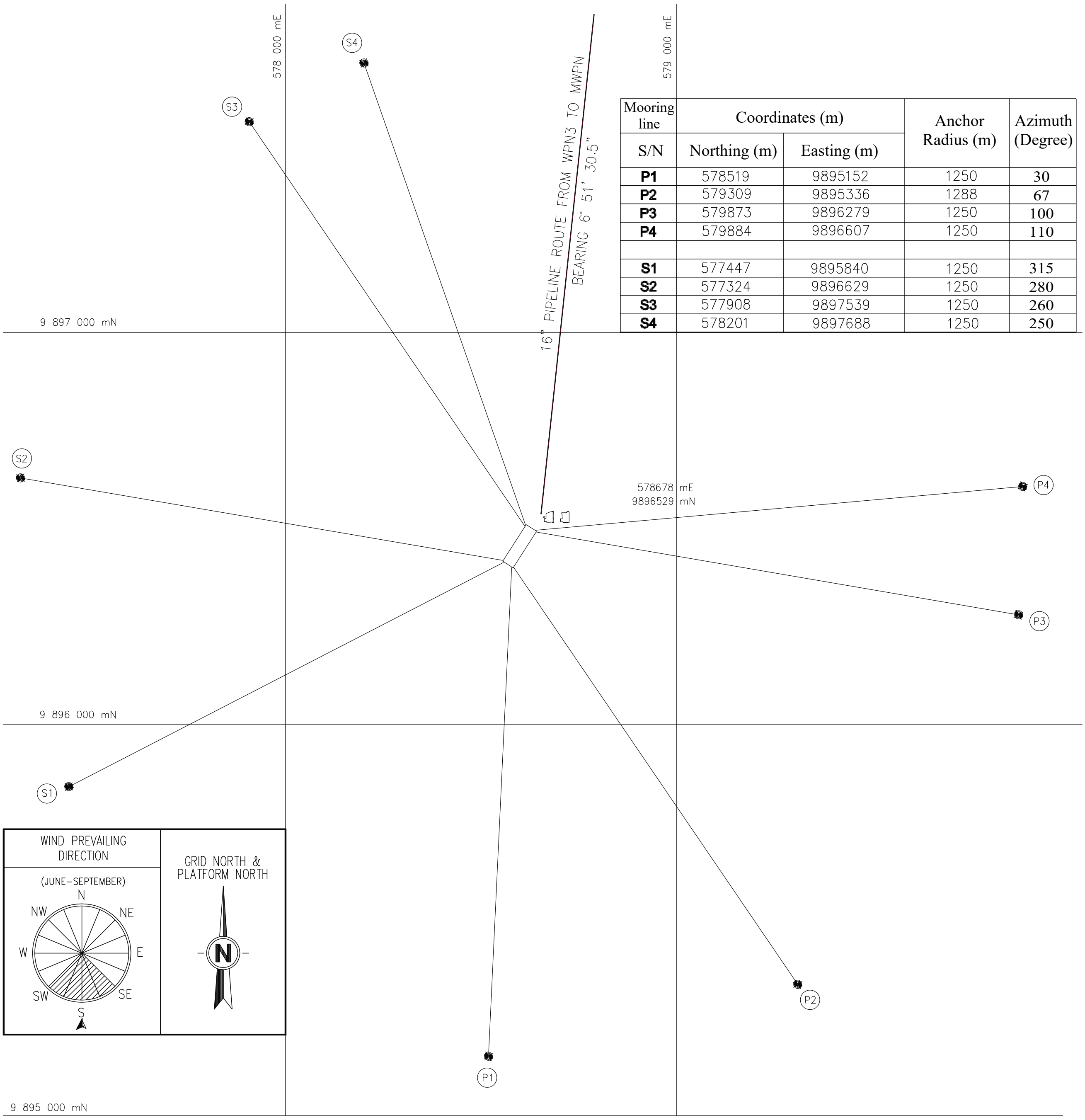
- General Alarm
  The general alarm on the ship is recognised by 7 short rings of the bell followed by a long ring or 7 short blasts on the ship's horn followed by one long blast. The general alarm is sounded to make the crew on board aware that an emergency has occurred.
- Fire Alarm
  A fire alarm is sounded as continuous ringing of the ship's electrical bell or continuous sounding of the ship's horn.
- Man Overboard Alarm
  When a man falls overboard, the ship internal alarm bell sounds 3 long rings and ship whistle will blow 3 long blasts to notify the crew onboard, and the other ships in the vicinity.
- Abandon Ship Alarm
  When the emergency situation onboard ship gets out of hand and the ship is no longer safe for crew on board the ship, the master of the ship can give a verbal Abandon ship order, but this alarm is never given in ship's bell or whistle. The general alarm is sounded and every body comes to the emergency muster station where the master or his substitute (chief Officer) gives a verbal order to abandon ship.

3 - Working from barges or moored vessels

A lot of diving projects are organized from barges and four-point mooring vessels. Barges are often used for installation projects necessitating powerful cranes and 4 points mooring vessels are commonly used for small projects. Nevertheless, the procedures for diving from these surface supports are similar.

3.1 - Mooring plan

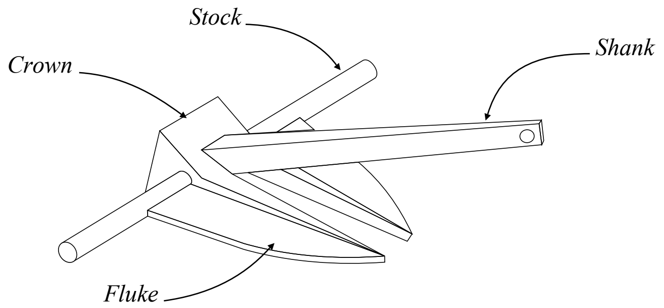
Mooring is not permitted in an oilfield without a mooring plan accepted by the client.
This plan indicates the pre-established position of the anchors, the mooring lines, the dangerous areas, and obstructions. An analysis of this mooring plan should be performed by specialists to predict the tension of the lines and the force applied to the anchors resulting from the environmental conditions on-site and other actions. It should indicate the maximum conditions the mooring can withstand considering the type of anchor used, the soil conditions, and the winches pull limits. This analysis should also take into account that manual adjustments of the lines are often performed for operational reasons or foreseeable environmental events. The method planned for dropping and retrieving the anchors should also be taken into consideration.



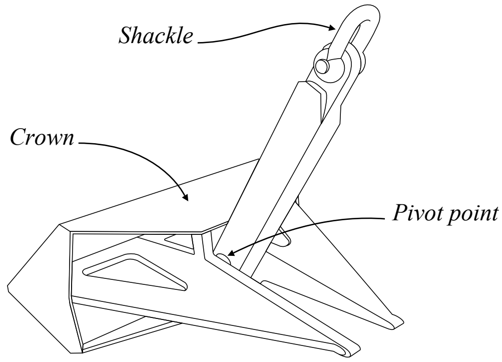
Mooring line	Coordinates (m)		Anchor Radius (m)	Azimuth (Degree)
S/N	Northing (m)	Easting (m)		
P1	578519	9895152	1250	30
P2	579309	9895336	1288	67
P3	579873	9896279	1250	100
P4	579884	9896607	1250	110
S1	577447	9895840	1250	315
S2	577324	9896629	1250	280
S3	577908	9897539	1250	260
S4	578201	9897688	1250	250

Barges and four-point mooring vessels generally use catenary moorings with drag anchors. A catenary mooring system consists of a line merely deployed from the ship to the bottom of the sea. The name "catenary" comes from the curve of the chain or cable due to its weight when supported between two points (for example, electrical lines between 2 posts). It is the most common mooring system in shallow waters.

Drag anchor holding capacity is calculated in the function of several factors, such as the anchor type and its behavior during deployment. Regarding this point, a lot of factors are considered, such as the opening of the flukes and their penetration in the seabed, the planned depth of burial of the anchor and its expected stability during dragging, the anticipated soil behavior over the anchor shape, and others. There are a lot of models of anchors that can be selected. Among the proposed solution, two models, the "Danforth* LWT" ("lightweight") and the "flipper delta", that are designed with the head pivoting at the extremity of the shank, are commonly employed on four-point mooring ships and barges *(* Danforth is a brand)*.

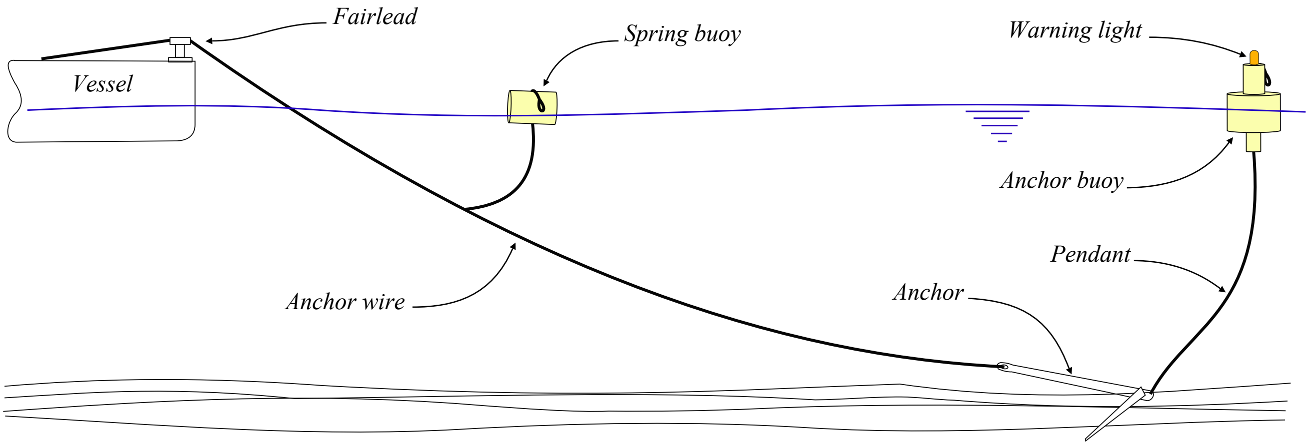


Danforth anchor



Flipper delta anchor

Anchor are connected through wire ropes (anchor wires) which are adjusted by the anchor winches of the barge or the support vessel. A line is attached to the crown (bottom end) of each anchor and connected to buoys to facilitate the recovery of the anchors. Some intermediate buoys (spring buoys) can be fitted on the line. The combination of one anchor, the attaching anchor wires, a crown line and an anchor buoy represents one “anchor leg”.



Regarding the elements listed above, note the following points:

- The mooring wire ropes should be certified by a recognized competent body, and be terminated by a resin or zinc-poured socket at the end of each rope section. Note that these cables do not have a fibre core.
- Spring buoys are usually designed to remain at the surface. They should have a maximum of 67 % of submergence and be compartmented to minimize the risk of sinking in the event of damage. In case that units are planned to be used under the surface of the water, they should be designed in accordance with a recognized standard for use at the maximum operational depth identified by the mooring analysis.
- The minimum clearances between the vessel or its mooring components and the oilfield installations may change from one client to another one. However, they must be in accordance with national regulations.
- Linked to above, a long drag distance may be required for an anchor to reach full penetration and develop the ultimate holding capacity. EN ISO 19901-7 says that if the drag path of an anchor to a floating structure is expected to bring it within close proximity to another installation, the final anchor position should be such as to allow a margin of at least 300 m of drag before contact can occur with the installation. Otherwise, the final anchor position should be at least 100 m from the installation.
- EN ISO 19901-7 also says that when a mooring line within the elevated part of its catenary crosses a pipeline on the seafloor, a minimum vertical clearance of 10 m under the intact condition should be maintained. A mooring line may pass over and be in contact with a protected pipeline provided this contact is not interrupted throughout the full range of predicted intact line tensions, in other words, the contact does not occur in the thrash zone. Note that when pipelines and other service lines such as power cables are planned to be in contact with mooring lines, they are usually protected using a mattress or protection frames commonly called “sleepers”.
- The ship crew must be able to know the tension in the lines and the lengths paid out. For this reason, the vessel should be equipped with a calibrated system for measuring the tension and the length of cable paid out of each mooring line. That should be displayed at least on or near each winch. Note that these displays are generally provided on the bridge. Also, a heading device (gyrocompass) is mandatory.
- The anchors are deployed and recovered by one or several Anchor Handling Tug Supply Vessels (AHTS).

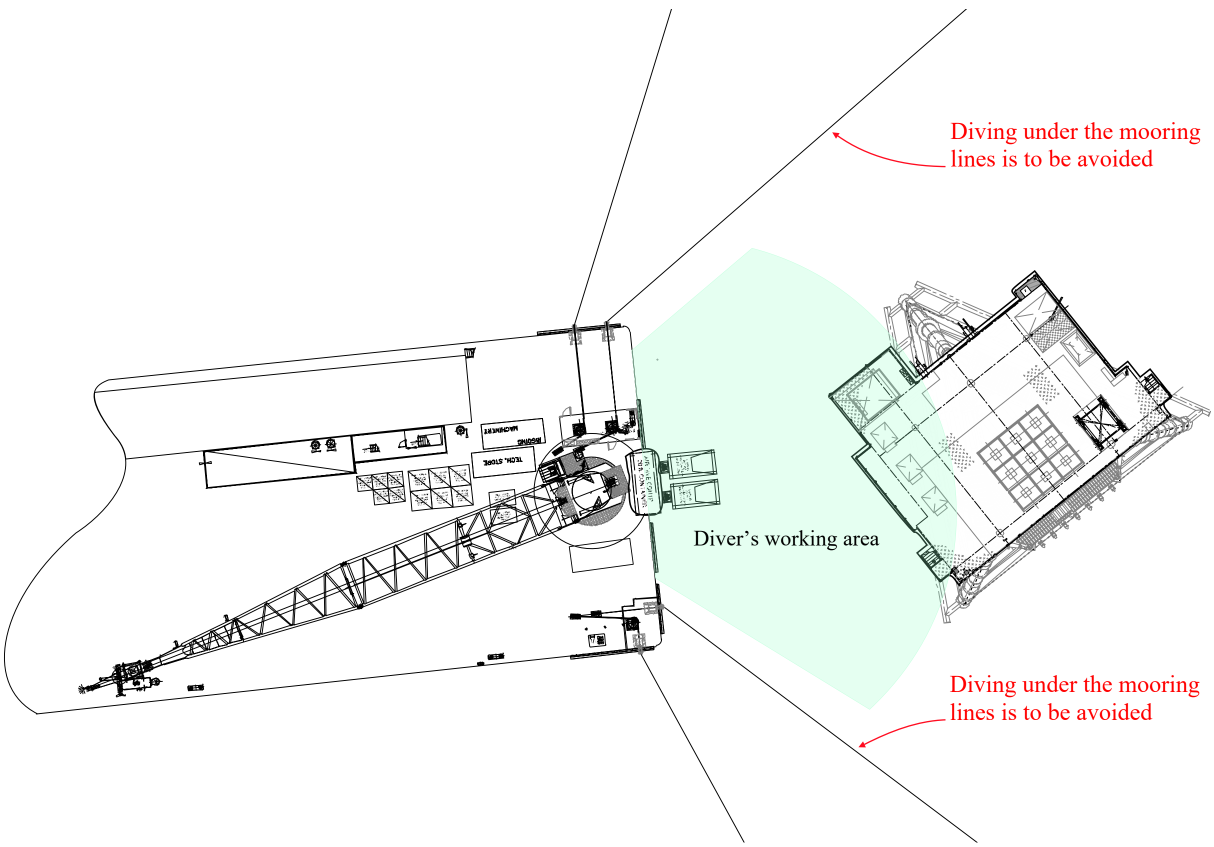
Diving projects generally consist of installation or repair jobs that do not require to change too much the position of the surface support. For this reason, one or two mooring plans are usually sufficient to perform the project. However, barges carrying out pipeline or cable laying use their anchor winches to move forward, which obliges to continuously reposition the anchors according to the progression of the barge. In this case, mooring plans for each phase of the project have to be provided.
The anchoring of a moored vessel is the responsibility of the vessel master, the surveyors, and the Offshore Construction Manager. This phase is normally closely monitored by the client.

3.2 - Diving from a four-point mooring vessel or a barge in a static position

3.2.1 - Preparation

Diving from a barge or a four-point mooring is usually not as complicated as from dynamic positioning vessels, because they are stable surface supports that are static. However, some safety rules have to be implemented:

- There must be a main and back up means of communications between the dive control, the bridge, and the other parts of the vessel.
- The mooring must be completed before starting the dives, and the mooring lines must have been inspected, particularly in areas where wear is likely, such as the fairleads.
- The mooring lines must be secured, and their tension must conform to what is planned in the mooring plan.
- The position of the anchors and the anchor lines must be displayed in the dive control.
- To minimise the transfers underwater, the vessel must be as close as reasonably practicable to the work site. IMCA D 022, section 10.3 indicates that the following factors should be considered:
    - The distance of the job from the proposed bell/basket location.
    - The maximum duration of the divers' bailout systems at the planned depth: In case of loss of gas supply, the diver in trouble must be able to return to the bell/basket using his bailout system, which dictates the maximum distance he can be from the bell/basket.
    - The characteristics of the umbilical: An extended length of negatively buoyant umbilical tends to drag a diver down, while a bulky umbilical may pull him in the current
    - The condition of the worksite, including debris, rocks, or other obstructions which could impede the diver’s return to the bell/basket in an emergency.
    - The unforeseen safety factors needed for particular situations such as loss of diver heating or trapped umbilicals.
- The mooring lines must not be above the job site to avoid injuries to the diver or trap him in case of a rupture.
- The water intakes near the dive station must be stopped or reduced (this must be included in the risk assessment)
- The position of the dive station must be assessed.



3.2.2 - Specific procedures to be in place during the dives

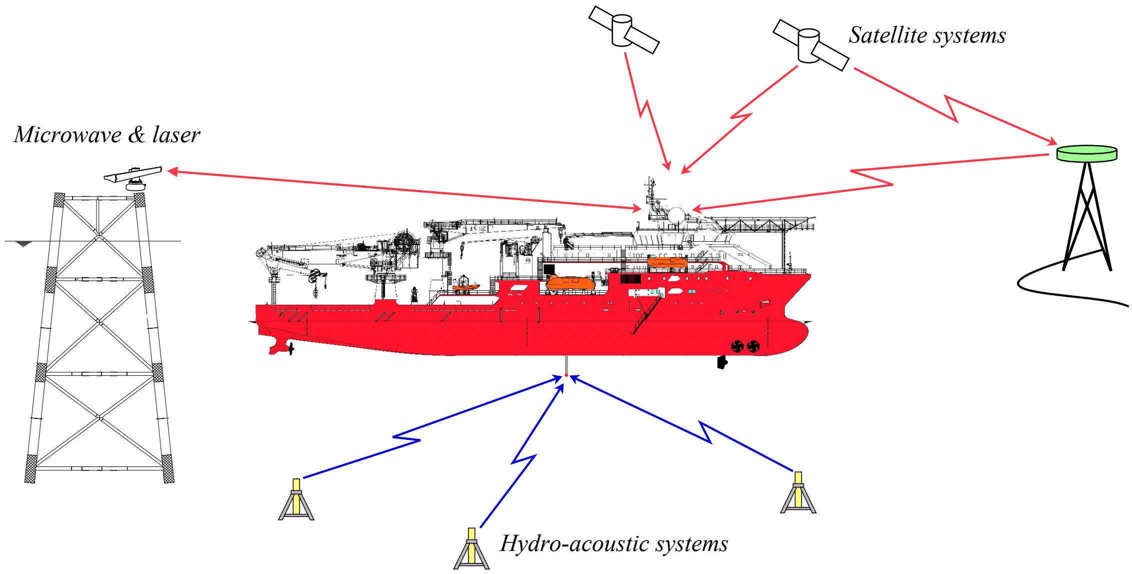
Diving from a barge often implies that simultaneous operations of teams preparing other phases of the project are ongoing. For this reason, the transfer of the diving team to and from the dive station must be secured as well as the dive station itself. Also, it often happens that barge crews are not familiar with diving projects.
For these reasons, it is crucial to ensure that the standard diving rules, indicated in this handbook, are understood by the barge crew and that relevant precautions are in place.
Also, specific procedures linked to the management of the mooring, and the fact that the surface support is static and cannot be quickly moved must be in place:

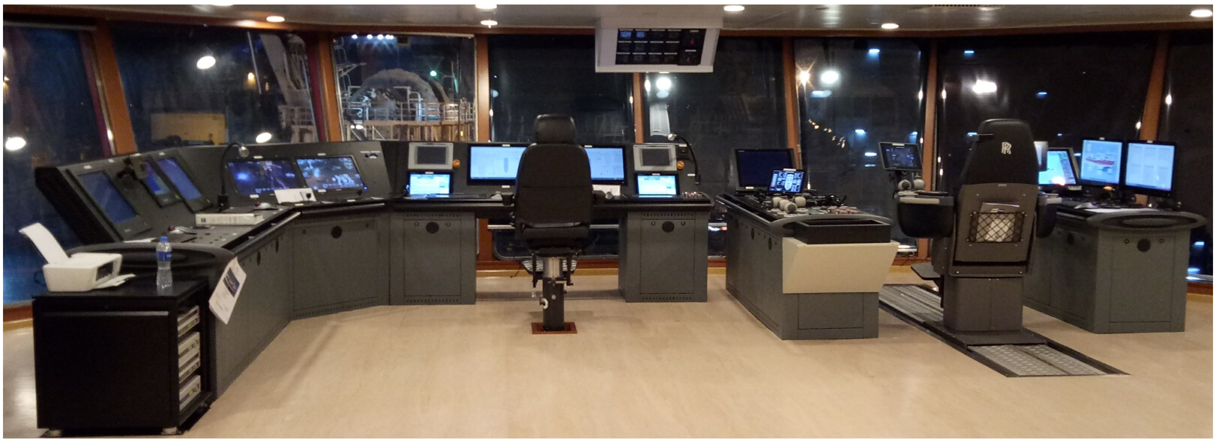
- The tension and wear of the mooring lines must be monitored at regular intervals, and any change regarding the status of the anchor legs must be indicated to the diving supervisor.
- As with every diving vessel, the weather conditions, and boats cruising at the proximity of the ship or the mooring lines must be indicated to the diving supervisor. Note that the diving supervisor has the authority to accept or reject vessels approaching the diving support vessel.
- If the vessel needs to be adjusted, the diving supervisor (and the divers) must be informed. Also, the movement must be safely executed:
    - The move is done slowly and step by step.
    - The divers' umbilicals are clear from any debris and obstruction.
    - The divers understand the move, and they are in a safe location that is not to be under a line.
    - The divers can easily return to the bell/basket.
    - The move can be stopped at any time.

4 - Diving from Dynamic Positioning (DP) vessels

4.1 - Purpose

Dynamic Positioning vessels are ships that automatically maintain their position and heading by using their propellers and thrusters through a computer-controlled machinery and position reference systems that are combined with environmental sensors and controlled from a specific station installed in the bridge of the vessel. Thus, these vessels do not require the usage of anchors to maintain their position and are ideal for various offshore operations, particularly those where dropping anchors would be complicated or impossible. Also, these ships provide excellent maneuverability compared with anchored ones and can quickly jump from one operation on a job site to another one in another place.
Dynamic Positioning systems are today used for all types of offshore activities. Except for very small passenger boats used for the transfer of personnel, we can say that ships operating offshore are equipped with this technology.
Note that the positioning reference used can be based on technologies using satellites, microwaves (radar), laser, and hydro-acoustic, that are described in the next point





Dynamic positioning control station UDS Picasso

4.2 - Basic design of a DP vessel

4.2.1 - Technical references

Dynamic positioning and propulsion systems are interdependent and are closely linked to the progress of the computing and electronic industries. So, they are among the elements of the ship that evolve the most quickly, and it is not rare that these systems are upgraded to new standards several times during the life of the vessel.
Four organizations, that are described in point 1.2 of this book, are known for providing guidelines and rules regarding the design and the use of dynamic positioning vessels:

- The International Maritime Organization (IMO);
- the International Marine Contractor Association (IMCA);
- the Diving Positioning Committee (DP Committee).
- The Association of Diving Contractors International (ADCI)

In addition to these organizations, manufacturers of propulsion and dynamic positioning systems publish guidelines to explain how their products should be ideally exploited. Also, the International Organization for Standardization (ISO) has published the document ISO 19901-7 *"Specific requirements for offshore structures - Part 7: Station keeping systems for floating offshore structures and mobile offshore units"*. However, this document does not speak of diving.

4.2.1.1 - IMO - Maritime Safety Committee circular 1580

The circular 1580 has been approved in June 2017 by the Maritime Safety Committee of the International Maritime Organization. This circular applies to all vessels built after the 9th of June 2017. It replaces the guidelines of the circular 645 published in 1994, that remains in force for ships constructed before the 9th of June 2017, except that the guidelines of section 4 "Operational requirements" of Circular 1580 apply to all vessels.
The purpose of these guidelines is to recommend the design criteria, equipment, operating provisions and testing as well as a documentation regime for dynamic positioning systems in order to reduce the risk to the personnel, the vessel, other vessels or structures, sub-sea installations and the environment, while performing operations under dynamic positioning Control. Note that it is the responsibility of the states where the boats are flagged to ensure that these guidelines are implemented.

4.2.1.2 - IMCA guidelines and incident reports

The procedures from this organization are based on those emitted by IMO to which complementary safety procedures and guidelines are added. The following documents exist that may be completed by new publications.

DP incident reports are indicated in the "Station keeping incidents" that are published every year.

4.2.1.3 - Dynamic positioning committee guidelines

The guidelines from this organization are also based on those emitted by IMO to which high level safety and technical procedures and studies are added. The organization also promotes some IMCA guidelines.

4.2.1.4 - ADCI guidelines

The Association of Diving Contractors International (ADCI) also provides some guidelines regarding diving from Dynamically Positioned vessels in section 4.3 of the publication "International consensus standards for commercial diving and underwater operations".

4.2.2 - Class of vessel

There are 3 classes indicating the capability of a vessel to maintain a position in the event of the failure of a component or an undesirable event such as a fire, a flooded compartment, and others:

- Class 1: Loss of position may occur in the event of a single fault.
- Class 2: Loss of position and heading should not occur from a single fault of an active component such as a generator or thrusters. It may occur after failure of a static component such as a cable, a pipe or manual valve.
- Class 3: Loss of position and heading should not occur for any single failure, including a complete burnt fire subdivision or flooded watertight compartment.

Regarding the selection of class for operations, the Dynamic Positioning Committee (DP Committee) lists the following minimum requirements. Note that requirements from some clients have been added in the remarks.

Operations	*Minimum class*	*Remarks*
Diving	2	Some clients may require class 3 for some operations
ROV in open water	1	Some clients may require class 2 for some operations
ROV at the proximity of an installation	2	Usually required inside the 500m limit
Drilling	2	
Pipe laying	2	
Lifting	2	Some clients may require class 3 for some operations
Floating production	2	
Accommodation	2	
Seismic and survey outside the 500 m zone	–	Class to be in accordance with the contractual requirements
Well stimulation	2	Vessels of lesser Class may be used with the appropriate structured risk identification and mitigation measures in place.
Logistics	2	

Comments regarding the selection of class for diving operations:

- The class does not refer to the power of the vessel. This point must be taken into account when selecting the surface support: Events have been reported where ships have lost their position during diving operations due to lack of power, particularly when the current was pushing them sideward.
- Vessels class 1 must not be used for diving operations.
- DP diving support vessels must be at least class 2.
- The class of vessel required must be decided during the preparation of the project, and must be risk assessed. Some clients may request a DP 3 vessel for the following operations:
    - Diving in an enclosed space such as inside a jacket, a Pipe Line End Manifold (PLEM), or any structure where there is a risk of having the diver endangered in case of a loss of position.
    - Diving in an Anchor pattern

4.2.3 - Power systems

IMO says that "power system" means all components and systems necessary to energise the DP system. This system includes but is not limited to: Prime movers with necessary auxiliary systems (including piping, fuel, cooling, pre-lubrication and lubrication, hydraulic, pre-heating, and pneumatic systems); Generators; Switchboards; Distribution systems (cabling and cable routing); Power supplies, including uninterruptible power supplies (UPS); and Power management system(s) (as appropriate).

4.2.3.1 - Propulsion and power supply systems commonly used

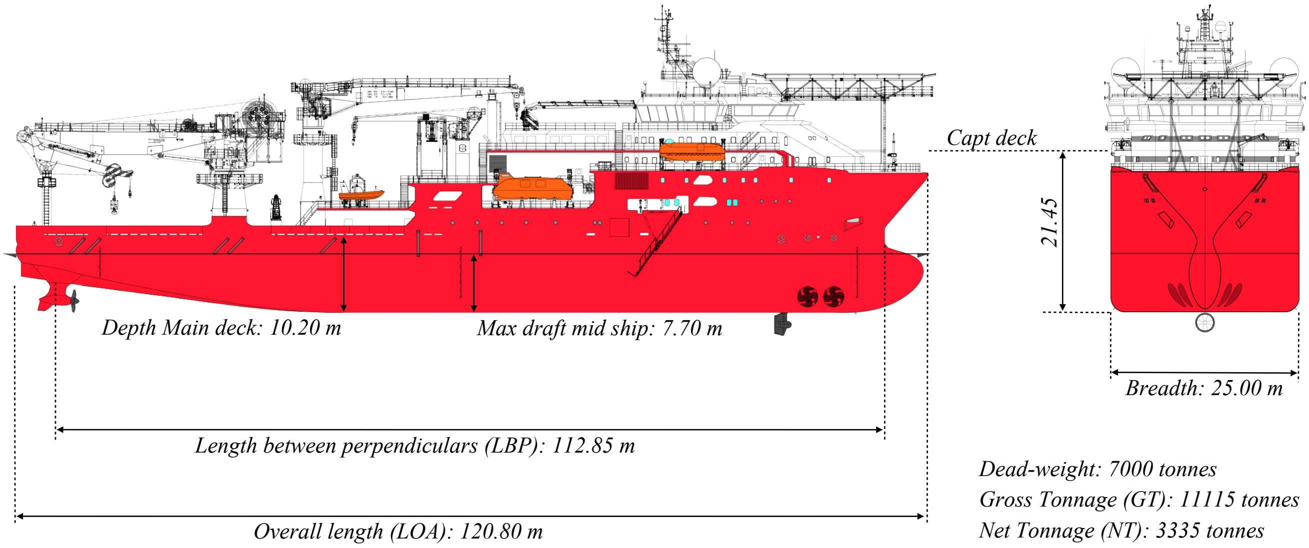
Recent dynamic positioning vessels use a diesel-electric propulsion, which means that they are powered by generators that energize the electric motors of the thrusters used for sailing, maneuvering, and keep the vessel in position when it is under dynamic positioning mode. These generators are also used to provide sufficient main and backup electrical supplies to the diving and ROV systems and to the other systems of the vessel.

Diesel-electric propulsion is not a new concept. As an example, "Emile Allard", a signalization buoys installer vessel built in Le Havre (France) in 1933 by Augustin Normand shipyard and sunk near Brest by the RAF the 14th of April 1943, was already propelled by two electric motors 447 kW powered by two diesel generators. The reason for this conception was that electrical motors were found more responsive and soft than thermal engines for the operations the boat was planned for. Also, diesel-electric propulsion has been used by German type XXI U-Boats that were built at the end of the second war and was the most modern submarines built during this period. Some of the advantages of this concept can be summarized as follows:

- A better control of fuel consumption and emissions due to the possibility to optimise the power delivered by the diesel engines according to the needs.
- As the vessel is powered by several powerful diesel generators, there is sufficient power delivered to continue to operate the vessel safely in the case of the failure of one of them.
- Improved manoeuvrability and station-keeping ability due to the increased availability and flexibility of the electrical motors. Note that an electric motor can provide its maximum torque at low speed while a thermal engine needs to rotate within a range below which the torque delivered is insufficient.
- The generators do not need to be adjacent and aligned with the shaft transmitting their motion to the propeller as the energy is transmitted to the electric motors of the thrusters by electrical cables. Also, electric motors take less space than thermal engines and they can be mounted in any position
- As there are less mechanical parts in movement, diesel-electric propulsion emits fewer vibrations and is more silent.

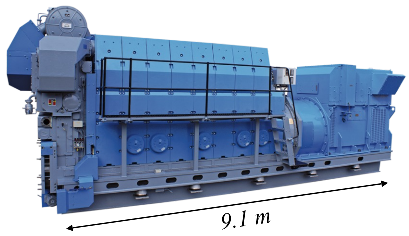
As an example of a recent unit using this system, Ultra Deep Solutions "Lichtenstein" is a DP 2 Diving Support Vessel (DSV) that has been designed by Marin Teknikk in Norway and built by China Merchant Industry Holdings Ltd.

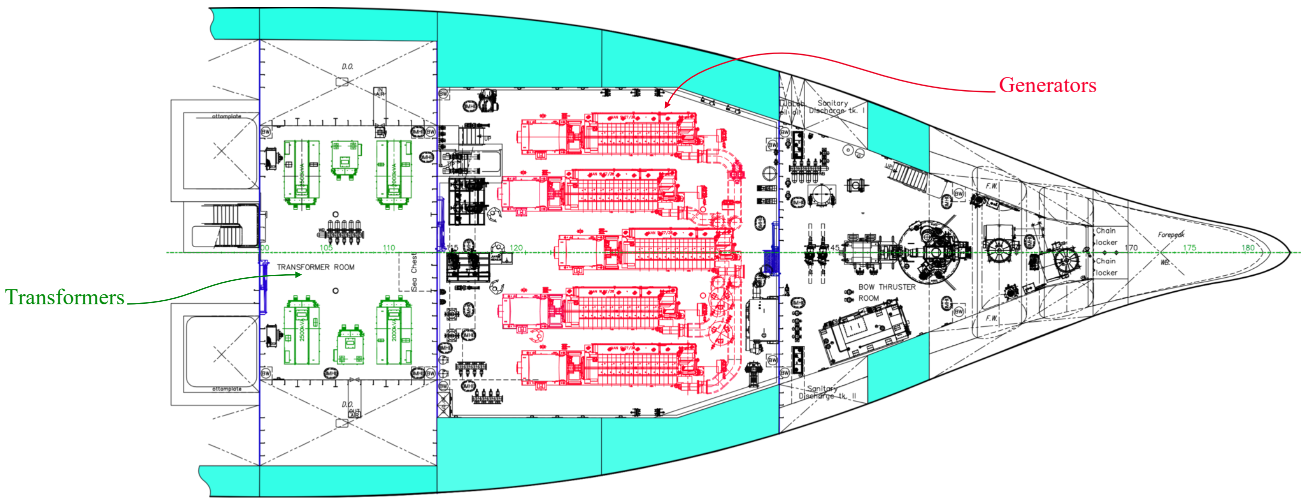
This vessel that has a deadweight of 7000 tonnes and a gross tonnage of 11115 tonnes for an overall length of 120.8 m is equipped with a twin bell saturation system designed for 18 divers *(NOTE: For the understanding of this diving system, refer to the document "Description of a saturation system")* and is designed for various tasks even those that require particular equipment such electrical cable installation, J-lay pipeline installation, or others.
For this reason, she is also equipped with an Active Heave Compensation (AHC) offshore crane that is designed to lift 140 ton at 12 m, a second subsea crane which can lift 40 ton at 35 m, and a third subsea crane 10 ton at 12.5 m that is installed on the mezzanine/ROV deck. Active and passive ship stabilization systems are provided.
These pieces of equipment and the propulsion systems of this ship are all energized by electricity.



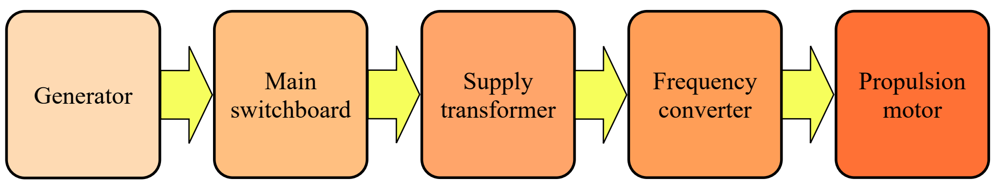
This electricity is produced by five diesel powered generators that are manufactured by Weichai Heavy Machinery co. Ltd. They are installed in a room situated in the lower parts and near the bow of the vessel.

- Each unit delivers 3168 KVA (2534.4 kw) at 720 r/min.
- The current delivered is 690 volts/60 hz. The electrical part (dynamo) model 1DB1036-8AY05-Z is designed by Siemens and assembled in China.
- The diesel engine is a Weichai-Man type 9L9738 that delivers 2970 kw (3983 hp) at 720 r/min. This engine is an in line four stoke 9 cylinders 21.8 litres/each.





The classical scheme of a diesel-electric propulsion is as follows:



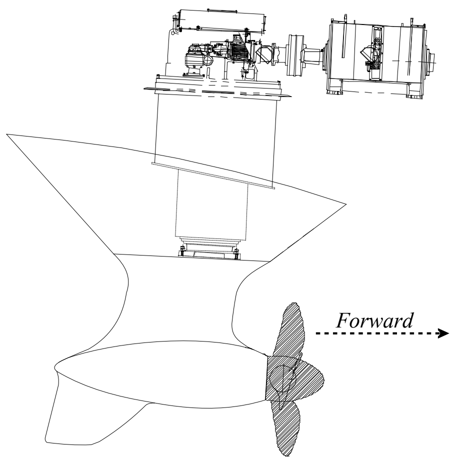
Definitions:

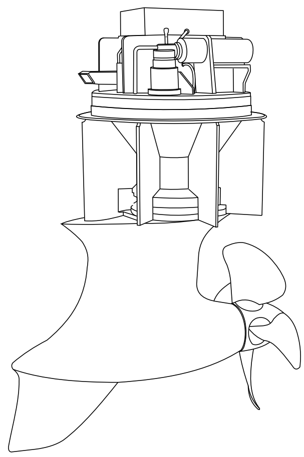
- *An electric switchboard is a device that directs electricity from one or more sources of supply to several smaller regions of usage. It is an assembly of one or more panels, each of which contains switches that allow electricity to be redirected.*

- *A transformer is a device used to change the voltage of an alternating current in one circuit to a different voltage in a second circuit. Transformers consist of a frame-like iron core that has a wire wound around each end. As a current enters the transformer through one of the coils, the magnetic field it produces causes the other coil to pick up the current. If there are more turns on the second coil than on the first coil, the outgoing current will have a higher voltage than the incoming current. This is called a step-up transformer. If there are fewer turns on the second coil than on the first, the outgoing current will have a lower voltage. This is called a step-down transformer. On Lichtenstein, some of the transformers are situated in the adjacent room and some others next to the thrusters.*
- *A frequency converter is a device that converts alternating current (AC) of one frequency to alternating currents of other frequencies. As the speed of an AC motor is dependent on the frequency of the AC power supply changing this frequency allows changing the motor speed. As a result, the rotational speed of the propeller can be adjusted using this means instead of using a gearbox, which allows saving energy.*

Lichtenstein is propelled, manoeuvred, and maintained into position by azimuth and tunnel thrusters. Azimuth thrusters tend to replace the classical fixed propellers driven by shafts to which diesel engines or electric motors are connected through specific gearboxes.

- Two stern azimuth thrusters Royce Rolls Azipul types developing 3500 kW *(4694 hp)* with a torque of 27854 Nm each are used to propel the vessel and maintain it in position while in dynamic positioning mode. The electric motor is energised by a current of 675 volts / 60.4 Hz.
  Opposite with classical azimuth thrusters, the propeller of the Azipull thruster is pulling instead of pushing, so the propeller works in the front of the mechanism as with most airplanes using propellers.
  The advantage of this system is that it combines the benefits of traditional propellers and classical azimuth thrusters. Thus, it offers a high manoeuvrability with the possibility to rotate 360º that is combined with low drag. Also, the pitch of the blades can be controlled, which gives the possibility to oriented them to move ahead or astern without changing the orientation of the thruster.
  this system avoids the installation of tunnel thrusters at the stern of the vessel as it is the case with classical propellers. Note that the four blades propeller is motioned by a mechanical drive system using bevel gears at the top and bottom of the leg. Power is fed to the unit through a horizontal input shaft within the hull, and the unit incorporates its steering motors for azimuthing. As every thruster used with the dynamic positioning system, each thruster is electronically controlled.

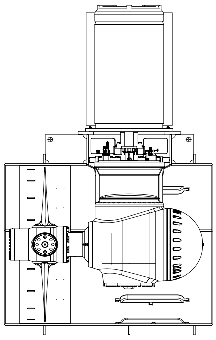
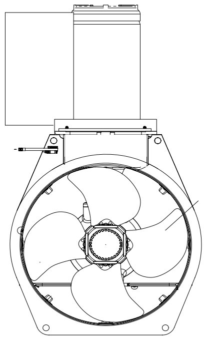
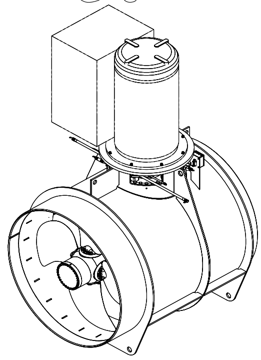




Topside parts of Azipull: Starboard side.

Topside parts of Azipull: portside.

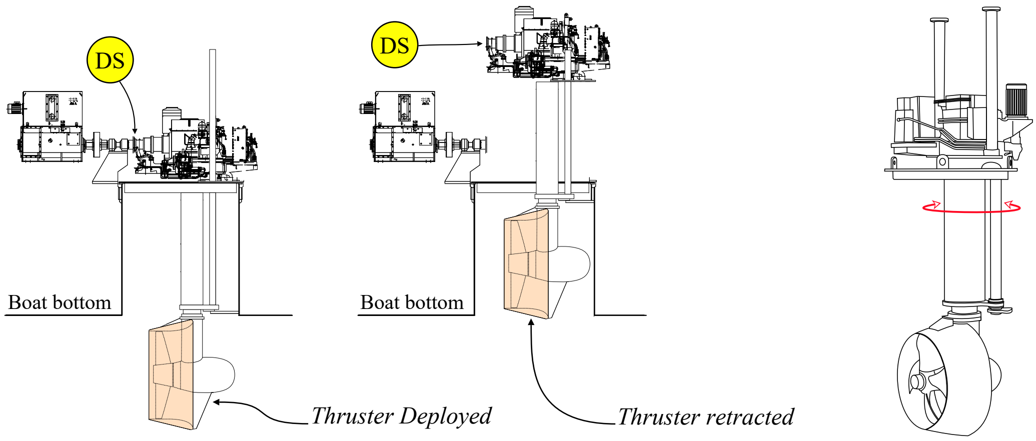
- Two bow tunnel thrusters Rolls-Royce TT2650 DPN CP, delivering 1910 kW (2588 hp) with a torque of 20479 Nm each, are installed to give a side force when maneuvering the ship or maintaining it in position while under dynamic positioning control. Their four blade propellers of 2.65 m diameter are equipped with a controllable pitch which allows to fully orientate them to push the vessel from one side to the other without changing the direction of the rotation of the motor. As with the thrusters at the stern, the motion is transmitted to the propeller by the means of gears.

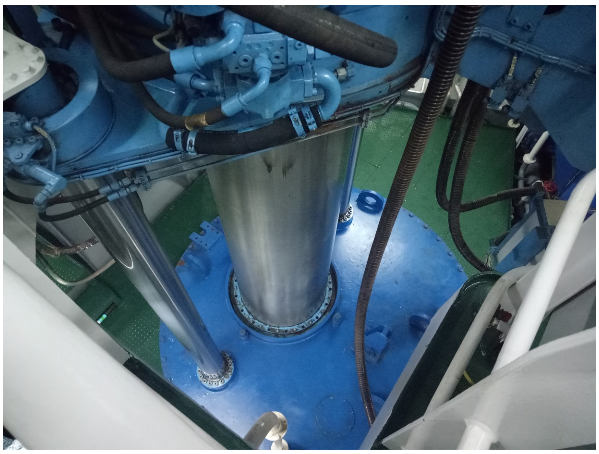

Upper parts of the tunnel thrusters of UDS Lichtenstein


Tunnel thrusters of UDS Van Gogh

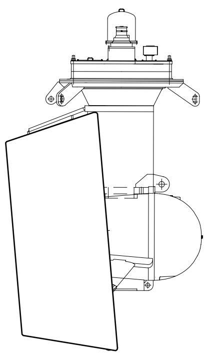
- To complete the force of the two tunnel thrusters, one azimuth retractable thruster 1500 kW *(2011 hp)* is installed at the bow. This azimuth thruster, which is manufactured by Rolls-Royce, can rotate 360º and gives more control and flexibility to manoeuvre the vessel and maintain it in position when operating in dynamic positioning mode. Note that this thruster is equipped with a four blades fixed pitch propeller of 2.3 m diameter. The advantage of a retractable thruster is that it improves the hydrodynamics of the ship during the transits and also protects the thruster that is lifted in its casing when it is not in use. The thruster is deployed using hydraulic jacks. The internal mechanism is similar to the models described above. However, to protect the mechanism and avoid uncontrolled manoeuvres, the drive shaft (DS) is automatically disconnected when the thruster is lifted up.

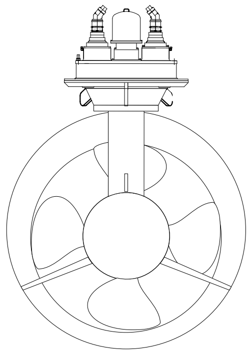


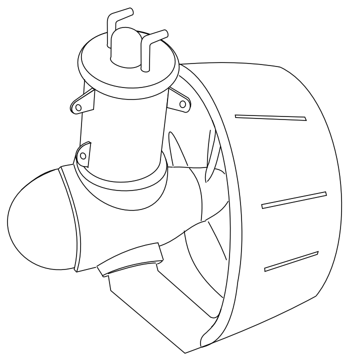
Thruster retracted: Upper parts


Thruster retracted: downward view from the upper parts

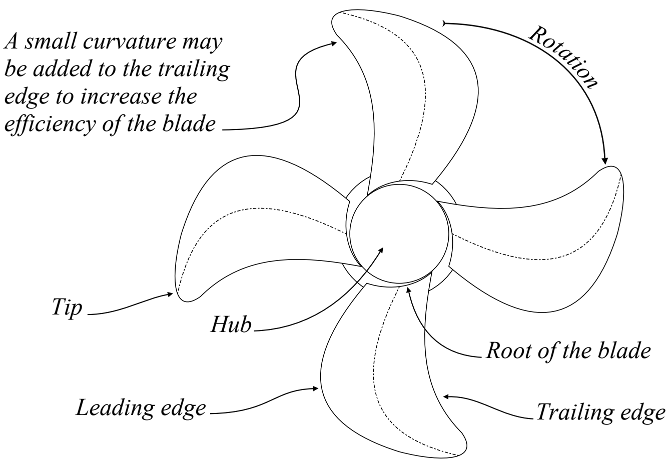
- Note that propulsion thrusters with nozzle are commonly installed in place of Azipull on a lot of ships. It is the case of UDS "Van Gogh" in the photo below. With this system, the propeller is surrounded by a nozzle that canalises the water flow to and from the propeller.

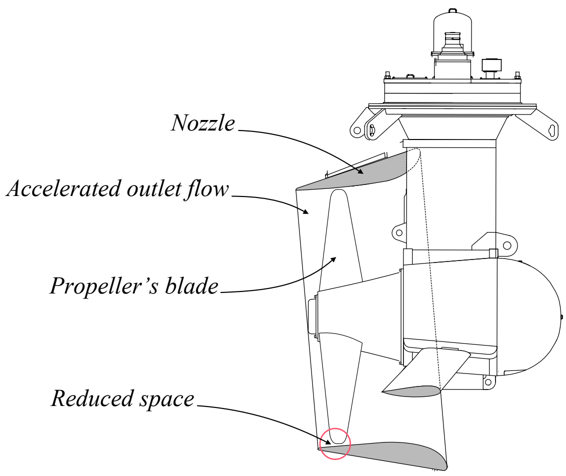




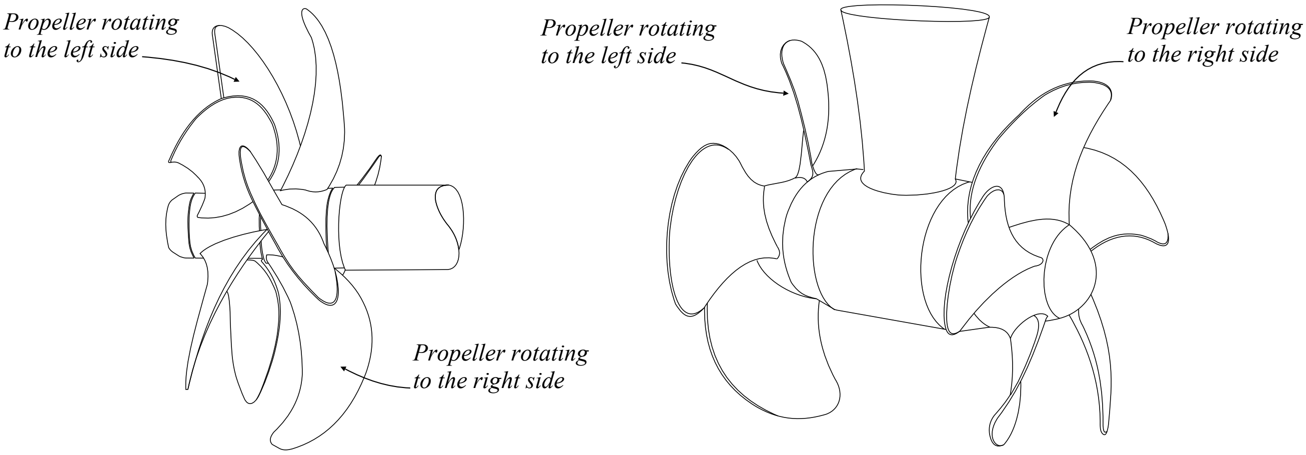


Several types of propellers can be used:
The propeller acts in the water similarly as a screw in a solid material, so it transforms the rotational movement of the engine or the electric motor into rectilinear motion.
The propellers have evolved since the first models, and the manufacturers continue to enhance their efficiency. One of the problems to solve is the loss of energy at the tips of the blades, which can be corrected by elaborate shapes. Another system to fix this problem is the installation of a nozzle around the propeller with a limited gap with the extremities of the blades to reduce the vortices and the effects of cavitation at their tips. Another advantage of the nozzle is that it increases the velocity of the water flow, and so allows for a more efficient thrust than a standard propeller. However, the nozzle creates additional friction to the water, which increases with speed. For this reason, specialists say that propellers fitted with a nozzle are ideal for providing high pulling power, but are not suited for high-speed ships.

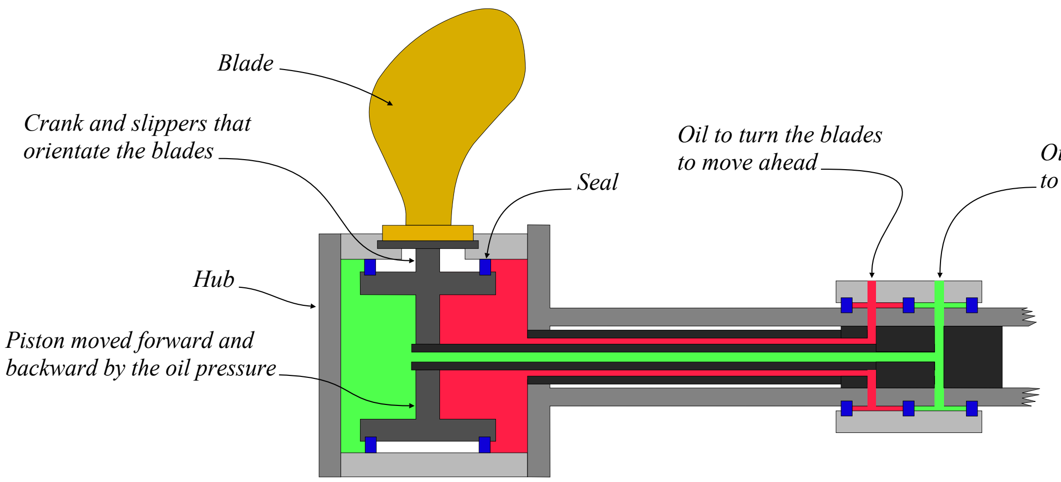


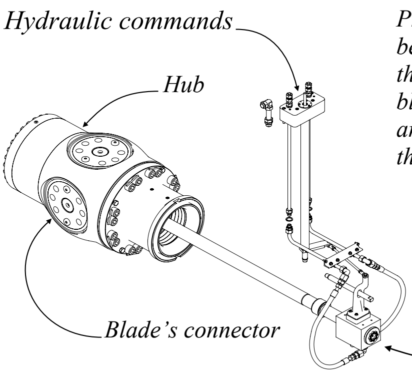


Note that it is said that the propulsive efficiency can also be increased by installing propellers with large diameters. However, the size of the propeller is limited by the draught of the vessel, and propellers of large diameters generate more constraints. For this reason, an alternative design that can be used is to increase the number of blades of the propeller.
Contra-rotating propellers is another solution proposed by the manufacturers for increasing the efficiency of the propulsion. This system consists of two propellers situated one behind the other and rotating in opposite directions. It provides the advantage of recovering a part of the slipstream energy of the 1st propeller, which would otherwise be lost with a conventional single-screw system. Furthermore, because of the two propeller configuration, contra-rotating propellers possess a capability for balancing the torque reaction from the propulsion. Militaries have used this system for a very long time for this reason and because it allows for high speeds.

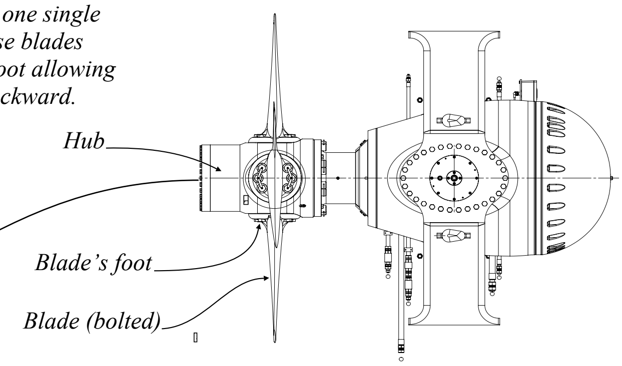


In complement of the designs indicated above, propellers can be equipped with a variable pitch controlling system. It is the case of the thrusters of UDS Lichtenstein that are described in the previous page.
With classical fixed pitch propellers, the blades cannot be orientated, and its propulsive forces are limited to only one ideal configuration, which leads to power wastage and increased stresses when the propeller is used outside the limits of this configuration. These stresses and loss of power can be prevented by changing the pitch of the propeller, so the propeller can be adapted to sail at an elevated speed, perform works that require high thrust, or be oriented to move backward without changing the direction of rotation of the propeller. Thus, this system avoids constraints on the gears and the electric motor or the diesel engine. Another advantage of this system is that because the propeller can be optimised for the working conditions, vibrations and noise are minimized.
The blades are usually oriented hydraulically by a piston that moves forward and backward. Also, an electronic system allows controlling the mechanism that can be operated from the engine room and the bridge. Note that in case the control system fails, the blades can be locked in the ahead position with the help of a locking device.





Propellers with variable pitch can easily be identified as their blades are added to the hub and not cast with it in one single block like standard units. These blades are provided with a circular foot allowing them to rotate forward and backward.



Acoustic reference systems are used for positioning control systems on the majority of DP vessels. For this reason, the Dynamic Positioning Committee says that the prevention of any acoustic interference between the reference systems and the noises generated by the propulsion devices is mandatory. Three different sources of noises are reported:

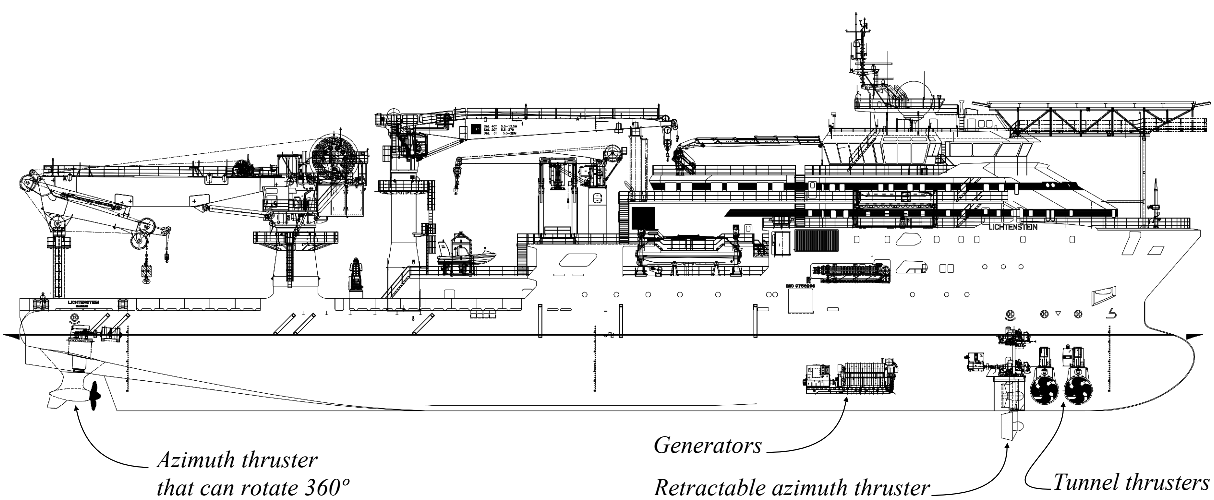
1. Cavitation results from the modification of the flow along with the propeller blades. It occurs when the pressure in certain places in the flow field decreases below the vapour pressure of the fluid. That leads to a reduction of the efficiency of the propeller, triggers the formation of tiny bubbles that implode and can damage the propeller's blades, and the emission of noises. These problems can be minimized by:
    - Installing the propeller as deeply as possible to increase the static pressure acting upon the propeller;
    - providing hydrodynamic shapes to the hull and elements situated inflow to the propeller;
    - avoid install propellers with oblique inflow angles;
    - Optimising the profile of the blades, and/or install a nozzle around the propeller (indicated before);
    - Cleaning and polishing the surfaces of the propeller and the elements situated at its inflow.
2. The singing of the propeller is a critical vibration phenomenon of the blades, which results in a high-pitched noise similar to the one made by a crystal glass. These harmonics are the result of many factors, such as the diameter, the thickness, and the profiles of the edges of the propeller's blades. This problem is usually solved by an anti-singing edge, which is a chamfer that is made on the suction side of the propeller, near the trailing edge of the blades, that cleanly separates the flow running off and so avoid the creation of the curving flow eddies at the origin of such parasite vibrations.
3. Noise created by the propeller jet: The Dynamic Positioning Committee says that thruster propellers installed under the bottom of the hull are commonly associated with this problem that is the result of accelerated water masses leaving the propeller/nozzle with a high velocity shed along the bottom of the hull. These noises may interfere with the acoustic positioning system, and can be magnified if the hydrophones are located in or near the passage of the jet. The interference may be reduced by the strategic placement of the hydrophones outside of the jet path or a deflection of the jet at a downward angle away from the hull. Installing guide vanes in the nozzle exit or tilting the propeller axis to a certain extent can deflect the jet.

The presentation of the propulsion systems of existing vessels in the previous pages shows that a lot of solutions exist that can be used for ships but that their selection to obtain an ideal dynamic positioning diving support vessel is not easy and usually result in a compromise. Regarding this point, the Dynamic Positioning Committee says the following in the document “Principle aspects of Thruster selection”:

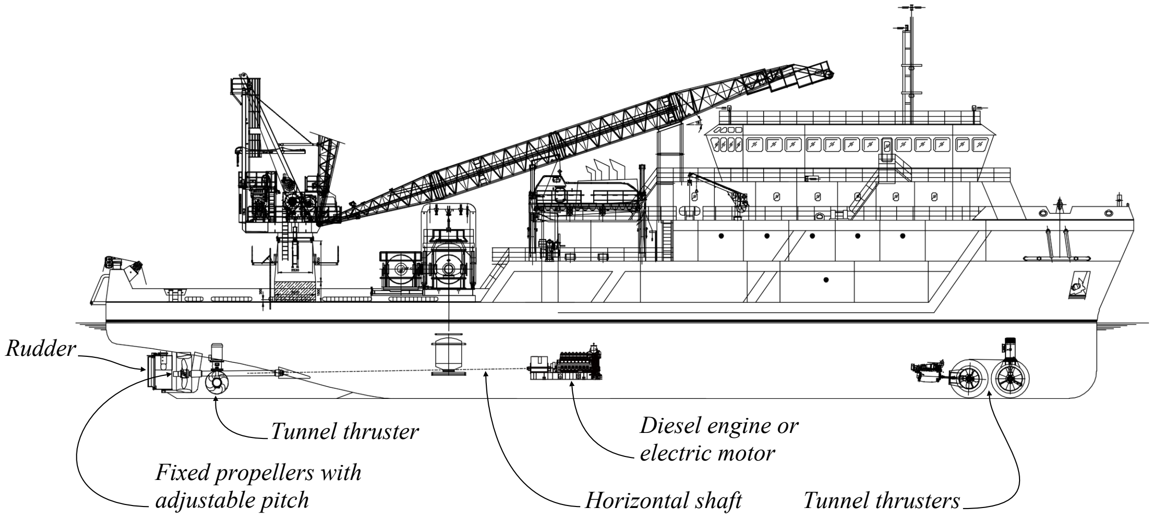
- A propulsion system applied for dynamic positioning of vessels must be able to generate counter forces against environmental forces such as wind, current, and waves, as well as forces resulting from the drag of a deployed array, pipes, risers, etc. during station-keeping operations. Environmental forces are omni-directional; therefore, propulsion systems or devices must have the ability to generate thrust in the full 360 degrees. In order to move the vessel from location to location, the propulsion system installed on DP vessels needs to generate the conventional propulsion forces in the longitudinal direction of the vessel.
- A DP vessel, is designed to operate in and survive extreme environmental conditions, although statistically these conditions occur very rarely.
- During station-keeping at very low inflow velocities, the propellers’ torque characteristic is very different from the characteristic at transit speed. It is very difficult for many propeller/drive machinery combinations to match their characteristics for these two modes.
- The thrust generated by the propulsion devices must be continuous and controllable in step-less increments over the entire operating range, from zero to maximum power in both directions of operation.

To summarize what is developed previously, two main types of configuration can be found with Diving Support Vessels:

- Vessels with azimuth thrusters for the main propulsion, and tunnel thrusters for the lateral propulsion of the bow, plus a retractable azimuth thruster installed near the bow to increase the manoeuvrability of the ship. The propulsive trusters can rotate 360º, and can be of Azipul type, or equipped with a nozzle, or provided with contra-rotating propellers. Such configurations are the most efficient, and those that are commonly found with last generation Diving Support Vessels (DSV) and many kinds of modern ships, including large boats.



- Vessels propelled by two fixed propellers with adjustable pitch, connected to electric motors or diesel engines by classical horizontal shafts, and equipped with tunnel thrusters at the bow and the stern of the boat for the lateral propulsion. A retractable thruster can also be provided as an option. The main propellers can be equipped with nozzles, or be of contra-rotating types. Such configuration is encountered with some Diving Support Vessels (DSV) of the previous generation, and a lot of multipurpose ships that can be used as temporary surface supports for portable diving systems.
  Regarding the motorization, the Dynamic Positioning Committee says that although typical diesel-driven propulsion arrangement is employed with the majority of commercial vessels, it is the less desirable for dynamic positioning applications for the following reasons:
  - The Rotations Per Minute (RPM) of the engine cannot be controlled below a certain minimum (the engine idling RPM is approximately 40% to 50% of rated RPM).
  - Increased engine maintenance problems occur when operating a Diesel engine continuously at lower power levels (lower than 50% to 60% of rated power for many engines).
  - The Diesel engine is able to match the torque characteristic of the propeller only at the design point, so, at full rated power.



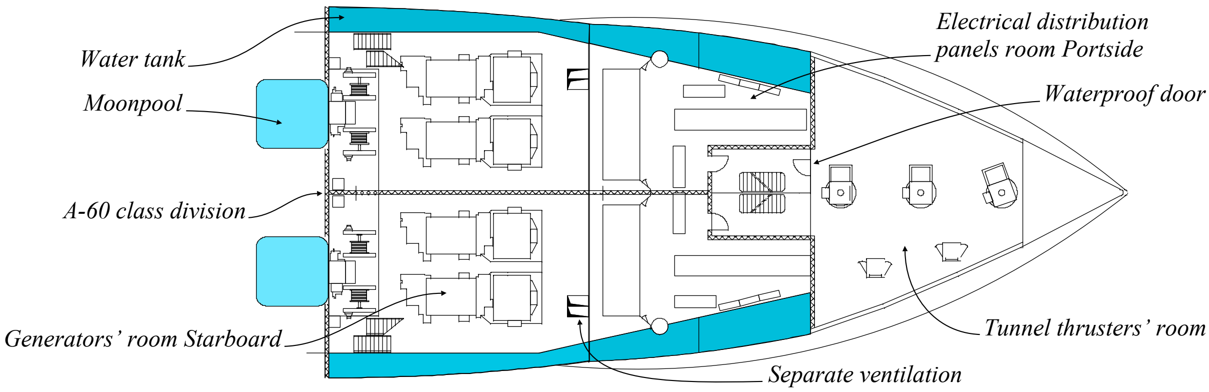
4.2.3.2 - Requirements from the International Maritime Organization (IMO) regarding power and thruster systems

The requirements from IMO Maritime Safety Committee Circular 1580 are international standards that are valid everywhere in the world and on which the standards of other organizations are built.

Regarding the power systems of vessels that can be used for diving, so class 2 and 3, it is said the following:

- For equipment class 2, the power system should be divisible into two or more systems so that, in the event of failure of one sub-system, at least one other system will remain in operation and provide sufficient power for station keeping.
  The power system(s) may be run as one system during operation, but should be arranged by bus-tie breaker(s) to separate the systems automatically upon failures which could be transferred from one system to another, including, but not limited to, overloading and short circuits.
- For equipment class 3, the power system should be divisible into two or more systems so that, in the event of failure of one system, at least one other system will remain in operation and provide sufficient power for station keeping. The divided power system should be located in different spaces separated by “A-60 class divisions”.
  An “A-60 Class Division” means a bulkhead or part of a deck which is:
  - Constructed of steel or other equivalent material and suitably stiffened;
  - constructed as to be capable of preventing the passage of smoke and flame for 60 minutes, and insulated with suitable non-combustible materials, so that the average temperature on the unexposed side of the division does not increase more than 139°C above the initial temperature within 60 minutes.

  If the power systems are located below the operational waterline, the separation should also be watertight.



- The power available for position keeping should be sufficient to maintain the vessel in position after worst-case failure. Also, at least one automatic power management system (PMS) should be provided and should have redundancy according to the equipment class and a blackout prevention function.
  Alternative energy storage (batteries and fly-wheels) may be used as sources of power to thrusters as long as all relevant redundancy, independency and separation requirements for the relevant notation are complied with.
- Sudden load changes resulting from single faults or equipment failures should not create a blackout.

Regarding the thruster systems of vessels class 2 and 3, it is said the following:

- Each thruster on a DP system should be capable of being remote-controlled individually, independently of the DP control system.
- The thruster system should provide adequate thrust in longitudinal and lateral directions, and provide yawing moment for heading control. The thruster system should be connected to the power system in such a way that it is operational even after failure of one of the constituent power systems and the thrusters connected to that system.
- The values of thruster force should be corrected for interference between thrusters and other effects which would reduce the effective force.
- Failure of a thruster system including pitch, azimuth, and/or speed control, should not cause an increase in thrust magnitude or change in the thrust direction.
- Individual thruster emergency stop systems should be arranged in the DP control station and should have loop monitoring. For equipment class 3, the effects of fire and flooding should be considered.
  Note: *A loop monitoring system operates hardware components and software control functions to monitor and regulate the devices, instrumentation, and machines in use in the vessel.*

4.2.4 - Position reference systems and sensors

4.2.4.1 - International Maritime Organization rules regarding the selection of reference systems and sensors

IMO Safety Committee Circular 1580 says that Position reference systems should be selected with due consideration to operational requirements, both with regard to restrictions caused by the manner of deployment and expected performance in working situations.

- The following requirements are mandatory regarding the position reference systems of diving support vessels:

- At least three independent references should be installed and simultaneously available. Also, they should not all be of the same type, but based on different principles and suitable for the operating conditions.
- The position reference systems should produce data with adequate accuracy and repeatability for the intended DP operation. They should be monitored, and warnings should be provided when the signals from the position reference systems are either incorrect or substantially degraded.
- For equipment class 3, at least one of the position reference systems should be connected directly to a backup control system and separated by an A-60 class division from the other position reference systems. Note that this backup control system is described in the next point.

- The following requirements are mandatory regarding the sensors of diving support vessels:

- Vessel sensors should at least measure vessel heading, vessel motions and wind speed and direction.
- When an equipment control system is fully dependent on correct signals from vessel sensors, these signals should be based on three systems serving the same purpose. So, 3 wind sensors, 3 heading reference sensors, and 3 motion reference sensors.
- Sensors for the same purpose which are connected to redundant systems should be arranged independently so that failure of one will not affect the others.
- For equipment class 3, one of each type of sensor should be connected directly to the backup DP control system, and should be separated by an A-60 class division from the other sensors. If the data from these sensors is passed to the main DP control system for their use, this system should be arranged so that a failure in the main DP control system cannot affect the integrity of the signals to the backup DP control system.

4.2.4.2 - Reference systems

4.2.4.2.1 - <u>Global Navigation Satellite System (GNSS):</u>

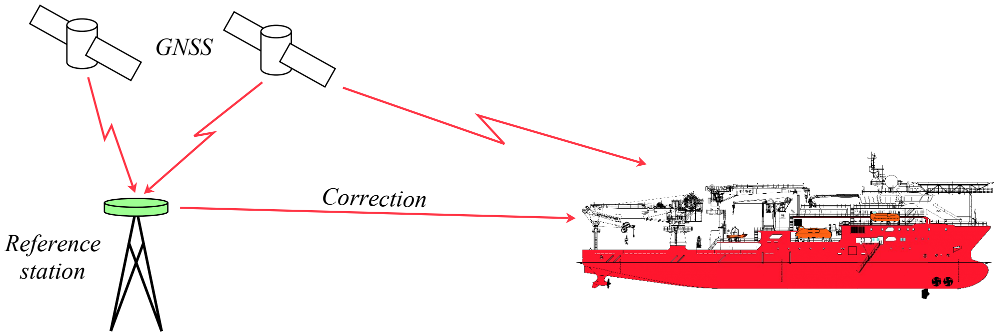
Global Navigation Satellite Systems have existed for many years and use cross-references from satellites to position vessels. The 1st system in use was the United States of America "Global Positioning System" (GPS), which is today based on 24 satellites, that can be complemented by onshore station references and is called Differential Global Positioning System (DGPS) in this case. Note that the primary usage of this system was for military purposes.
For several years other countries have developed alternative systems that are now available and can be used by these types of reference systems in replacements or the complement of the American GPS:

- GLONASS (Globalnaya Navigationnaya Sputnikovaya Sistema) is a Russian system that is an inheritance from the military system developed by the Soviet Union and uses 24 satellites.
- GALILEO system is developed by the European Space Agency for the European Union and associated states. The system that is not fully deployed will consist of 30 satellites, and is planned to be among the most accurate systems. Also, it can combine the data from its satellites with those of other networks.

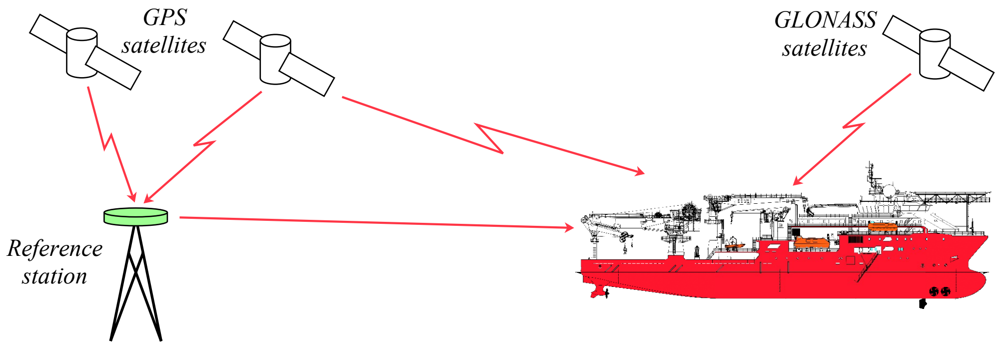
- BEIDOU (Běidǒu Wèixīng Dǎoháng Xìtǒng) is a Chinese satellite navigation system already active in Asia-Pacific that is planned to provide a global coverage by the end of 2020 and to be fully deployed end 2035 (5 geostationary, 27 in medium Earth orbit and 3 in Inclined Geosynchronous Orbit).
- QUASI-ZENITH SATELLITE SYSTEM is a four-satellite regional time transfer system and a satellite-based augmentation system development by the Japanese government to enhance the United States-operated Global Positioning System (GPS) in the Asia-Oceania regions, with a focus on Japan.
- IRNSS (Indian Regional Navigation Satellite System) is an independent regional navigation satellite system being developed by India. It is designed to provide accurate position information service to users in India as well as the region extending up to 1500 km from its boundary, which is its primary service area. An Extended Service Area lies between primary service area and area enclosed by the rectangle from Latitude 30 deg South to 50 deg North, Longitude 30 deg East to 130 deg East. IRNSS will provide two types of services, namely, Standard Positioning Service (SPS) which is provided to all the users and Restricted Service (RS), which is an encrypted service provided only to authorised users. The IRNSS System is expected to provide a position accuracy of better than 20 m in the primary service area.

Several modes of operations are applicable with Global Navigation Satellite Systems:

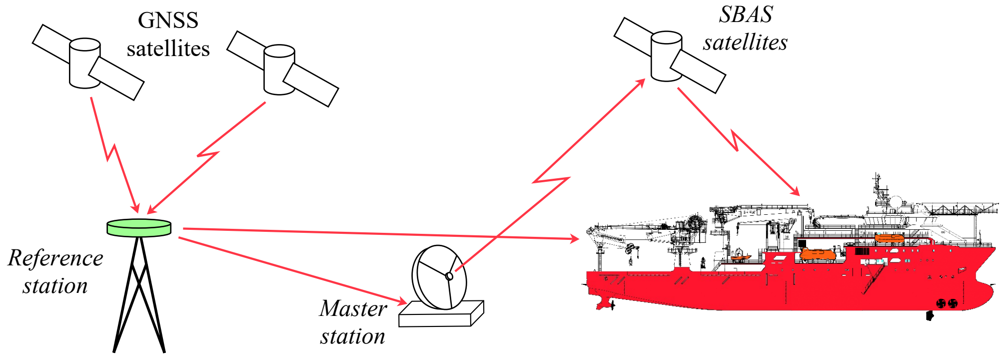
- "Differential GNSS":
  Such devices are based on the system already developed for American DGPS, that uses a network of fixed shore based reference stations to broadcast the difference between the positions indicated by the satellite systems and the known fixed positions. Using this system the improvement of the accuracy is from 15 -10 metres nominal GNSS accuracy to about 50 cm. This system is one of the most used, However some problems of accuracy can be encountered due to the following reasons:
  - GNSS and Differential signal interference due to satellite communications, and localized radio transmissions from civilian or military sources.
  - Physical obstructions blocking GNSS and differential signals, an example would be a DP vessel working alongside a platform that relocates to another face of the platform, and in the process loses all signals due to the platform obstructing the signals.



- Global Navigation Satellite System (GNSS) combined with Inertial navigation system (INS):
  Global Navigation Satellite System (GNSS) provides an acceptable accuracy when at least four satellites are connected to it. When the connection to one or several satellites is blocked by obstructions such as a platform or a floating facility, the positioning of the vessel is not sufficiently accurate to be used safely. A solution to avoid the problem is to combine the data from the Global Navigation Satellite System with those from an inertial navigation system.
  An "Inertial Navigation System" consists of accelerometers and gyros, that compose the "Inertial Measurement Unit" (IMU), which provides acceleration and angular velocity measurements that are used by a computer to calculate the position of the vessel according to a known starting point. Note that the Inertial Measurement Unit (IMU) is sometimes called the Inertial Reference Unit (IRU). When it is associated with it, the Global Navigation Satellite System is used to reset the starting point of the IMU periodically.
- Differential Global Navigation Satellite System (DGNSS) using the data of two different satellite networks:
  As an example, the Kongsberg DPS 232 is a Global Navigation Satellite System (GNSS) based position reference system using the American GPS with the Russian GLONASS to have more satellites available to fix positions more quickly and accurately, especially in areas where the view to some satellites is obscured by facilities. Note that GLONASS is also more suitable for use in high latitudes (especially North).

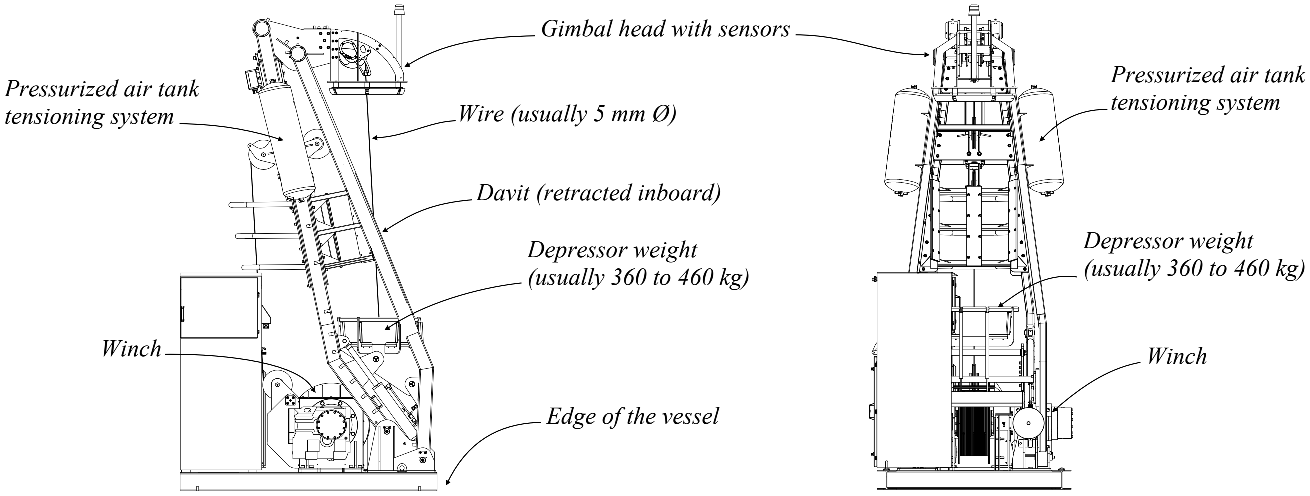


- SBAS (Satellite-Based Augmentation Service) system with a dual channel IALA (International Association of Lighthouse Authorities) beacon receiver:
  As an example of such a system, the Kongsberg DPS 132 uses GPS (Global Positioning System) with SBAS and IALA systems.
  - The "International Association of Lighthouse Authorities" (IALA) is an intergovernmental organization that collects and provides nautical expertise and recommendations that are used to install on-shore reference stations that are used to provide adequate correction to the variations in positions given by basic Global Navigation Satellite System (GNSS) signals.
  - Satellite Based Augmentation Systems (SBAS) are Geosynchronous satellite systems that provide services for improving the accuracy, integrity and availability of basic Global Navigation Satellite System (GNSS) signals.

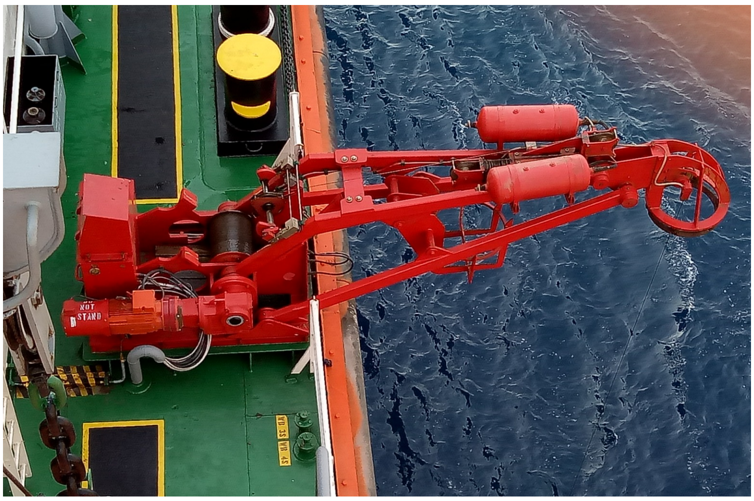


4.2.4.2.2 - *Taut wire:*

A taut wire is a vertical system consisting of a cable attached to a load deployed to the bottom using a davit or an A-frame. The wire is held in constant tension to remove vessel motion from the system through a powered winch. This winch may be pneumatically, hydraulically, or electrically actuated.
The angle of the cable is analyzed by sensors such as inclinometers, with calculation reference is the vertical, or by a potentiometer which calculation is made with respect to the davit. The position of the weight is calculated using these angles and the length of cable deployed (horizontal distance = distance of the sensors from the bottom of the sea multiplied by the tangent of the angle). When the angle of the cable is outside the set limits, an appropriate response is implemented to return it to its initial value.



Taut wire retracted (not working)



Taut wire deployed (at work)

The Diving positioning committee says that when the angles are calculated with respect to the davit, then they need to be compensated for roll and pitch so that on some vessels, all the position reference systems can be reliant on the measurements of the vertical reference units.

Taut wire systems are often used with diving support systems for the following reasons:

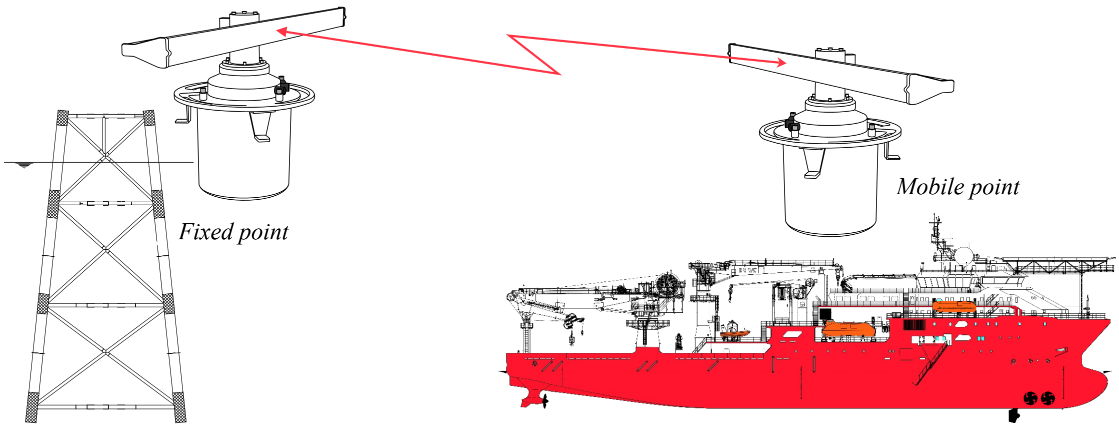
- The system is reliable and in use in the industry for decades.
- They are reputed robust and easy to maintain.
- They are easily deployed and recovered, and do not need any outside assistance.
- When correctly used, their accuracy is reputed to be very good.
- They are not affected by underwater noises such as those described in point 8.2.3.1.

Taut wires also have some inconveniences:

- Strong currents can create a catenary that may affect the accuracy of the system: A catenary is a curve made by cables held in two points that results from their weight (such as the curve of telegraphic cables between posts). Strong currents can create or increase such effect on the taut wire. The extend of catenary depends on the depth and the diameter of the cable (The deeper is the bottom, and the thicker is the cable, the bigger the catenary is). Manufacturers provide correction tables to control this problem.
- Snagging of the taut wire may happen during diving and ROV operations, and may result in problems such as a loss of position. For this reason, divers and ROV must be at a reasonable distance from the taut wire not to be snagged in it. Also, the taut wire should be clearly marked to distinguish it from the other cables, and its position must be indicated in the procedures and that navigation screens of the diving supervisor and ROV pilot.
- The weight can be trapped in debris laid on the bottom and be unable to be recovered. Also, it can be lowered on a sub-sea equipment and damage it. For these reasons, its deployment should be performed only in clean areas.
- The taut wire winch may be unable to follow the vessel movement in heavy seas.
- Taut wires are limited in-depth and are usually not designed to be used with bottoms exceeding 450 m. The Diving Positioning Committee says that some tests have been done at 800 and 1000 m, but these systems are not currently proposed.
- The vessel's movement is restricted to the range of angle measurement, often 30 degrees, or when the wire touches the vessel's side. In case the vessel is to be moved and/or the taut wire angle arrives at its limit, the weight must be relocated. However, IMCA says that re-plumbing a taut wire, when it is one of the three position references, does not constitute a violation of the requirements, if such action is completed as quickly as is safe and practicable, and the station keeping was stable when the taut wire was deselected prior to re-plumbing. Note that for any action on the taut wire, the diving supervisor is to be informed.

4.2.4.2.3 - Artemis Surface Reference System (Microwave link):

This system is classified among the microwave radar systems. It operates with very low power microwave transmissions (9.2 - 9.3 Ghz) using an antenna installed on a fixed point and a mobile antenna on the vessel. These antennae are similar to those of radars and can rotate to search for their counter stations. The position is determined by measuring the absolute distance and the relative angle between the two stations, so this system accurately measures the range and bearing of the vessel relative to the fixed position.



This system provides the following advantages

- Artemis is safe for use in zone 1. However, it should be switched off during radio silence or explosive work.
- The system usually has a range of 600 m, and its accuracy is up to 0.25 m and 0.2 degrees or better. It can be used during unfavourable sea conditions.
- New models are designed with automatic beacon and sensor acquisition.
- The system has tracking and data logging capability.

This system has the following inconveniences

- The old versions of the system accept the only signal of the DP vessel on which they are used.
- The system can have interference with other DP signals and radar. It can also have interference with objects like scaffoldings, pipes, containers.

An Artemis sensor can be checked without the need for a second unit using a specific tool called "validator".

4.2.4.2.4 - Fanbeam laser:

This system uses the principle of laser range finding by measuring the time taken for a pulse of laser light from the laser source to the target and back again, and hence deduces the distance of the target.
The system utilizes non-powered static targets that are intrinsically safe and can be easily mounted in almost all areas of an offshore platform or drilling rig. These targets are reflecting tubes or prismatic reflectors. The maximum operational range is about 2000 m for an accuracy of 20 cm. However, IMCA M 170 says that the combined repeatable bearing accuracy will limit the range at which stable position inputs can be obtained, suitable for automatic dynamic positioning. The maximum range for use with DP is therefore likely to be < 150 metres using reflective targets and < 500 metres using retro prisms.
This system is considered as a relatively cheap and transportable positioning reference for use in conjunction with other positioning reference systems for the dynamic positioning of marine vessels.
The size of the emitter/receptor is 260 X 300 X 297 mm, which allows for easy installation and transfer.

Despite its advantages note that the following inconveniences may be encountered:

- The system does not operate with sun shining into the lenses, or its performances are highly degraded in such conditions;
- The lenses can be affected by condensation, rain and salt spray;
- The operating range of the system is reduced in fog, snow or heavy rain;
- The system may become confused at night if there are bright lights close to the target. Or, it maybe interfered with by reflective items on the vessel or the platform; such as safety notices, reflective jackets, etc. However the manufacturer says that this problem has been corrected with the last models.
- Reflectors have to be installed on the facility, which may oblige to transfer personnel for this operation.

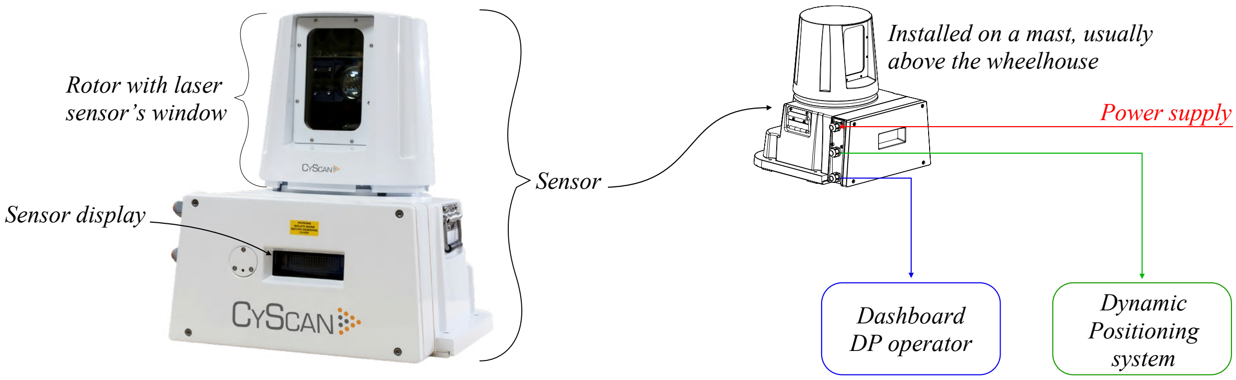
Reflecting tubes & prismatic reflectors

Laser emitter & receptor

4.2.4.2.5 - CyScan:

Similarly to Fanbeam laser, CyScan system operates on the principle of infra-red laser to pre-positioned reflector panels or prisms that can be installed on a structure or another vessel. This system is composed of:

- A sensor, which incorporates the rotating scanner head with laser optics, stabilization hardware and electronics for control, signal processing, and communications. It measures the range and bearing of the targets on 360.
- The "dashboard" that provides the DP operator with status information and control of the system and the data that are automatically transmitted to the vessel's DP system.
- The retro-reflectors consisting of reflective tape mounted on a flat or cylindrical support, or prismatic reflectors, that are similar to those used with the Fanbeam system.



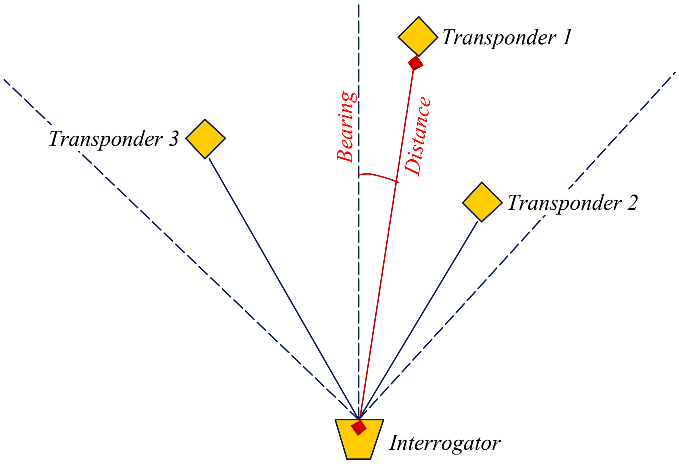
The manufacturer indicates an operational range up to 3250 m with an accuracy of 20 cm. However these performances are dependent on target size and atmospheric conditions, and IMCA M 170 says that the range is limited to 400 metres in the majority of operating environments.
The system can operate in single target and multi-targets modes. It does not rely on gyro compass input.
Like Fanbeam, it is considered as a relatively cheap and transportable positioning reference, for use in conjunction with other positioning reference systems for the dynamic positioning of marine vessels.

The inconveniences that have been reported with this system are similar to those of the Fanbeam system.

Note that regarding the installation of the reflectors, the manufacturer says that the targets should be placed in positions where the sensor can see them while the vessel is within the expected working area. Flat reflectors should not be too far along the structure from the expected working area as that can reduce the viewing angle for close operations that should not be above 45º. Also, the targets should be positioned with unequal spacing between them, and not closer than 5 m. Also, a permanent location of targets is recommended throughout the operations.

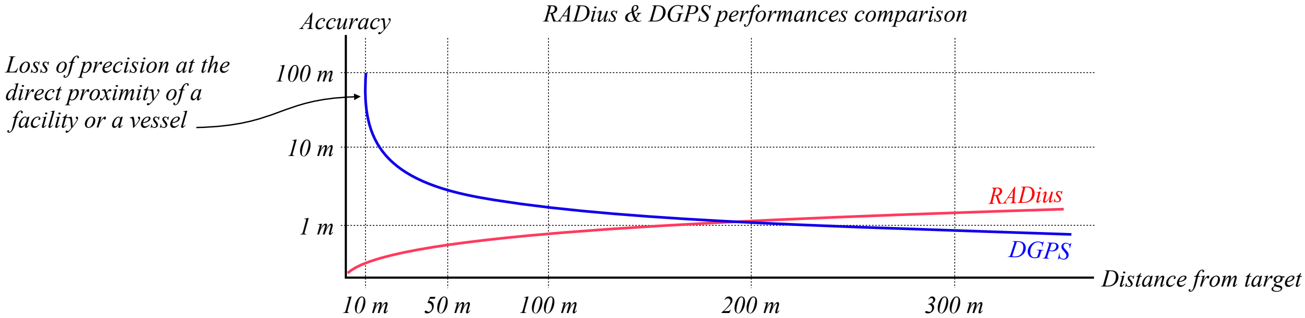
4.2.4.2.6 - RADius:

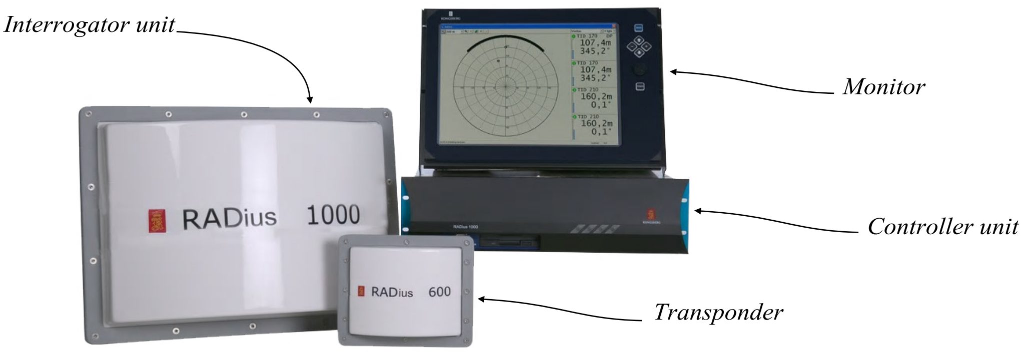
RADius is a relative position reference system developed by Kongsberg that utilises radar principles in short range and direction monitoring and is designed to operate in close proximity to structures and other vessels.
This system consists of an interrogator located on the DP vessel and one or several transponders with unique identity deployed on the target (vessel or installation). The RADius system measures distance and bearing from the interrogator to the transponders.



Differential Global Navigation Satellite Systems (DGNSS) suffer from a limited view of the sky when moving close to the structure. This can be crucial when the dynamic GNSS constellation is at its minimum and the most important satellite disappears behind the structure. Opposite of DGNSS, the RADius system increases its performance as the vessel moves closer to the transponders located on the structure. As a result, the RADius system can be used as a complement to the DGNSS system. It is composed of the following elements:

- The RADius interrogator unit is mounted outside on the vessel with free view to the horizon. It contains antenna elements, a receiver, a transmitter and a signal processing front end.
- The RADius controller unit is a 48 cm rack which contains the RADius processing unit that runs the final signal processing software, a graphical user interface and it provides serial interface lines to the DP and other possible users. The controller unit also contains keyboard and video display unit together with a power/connection module that provides network communication and power to the interrogator.



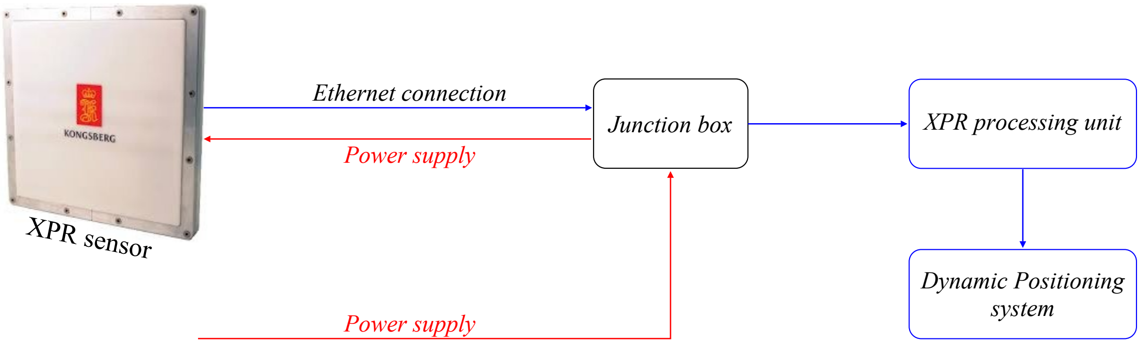


Operational advantages of the system:

- There are no motors, stabilized platforms or other moving parts within the system.
- It operates in all weather conditions and has wide opening angles both horizontally and vertically and will therefore be unaffected by high sea states.
- The system allows for multi user operability, which means that several vessels can utilize the same transponders simultaneously.
- It operates in a radio band that is allocated to marine radio navigation and is license free.
- The system efficiently mitigates radio interference. This is due to the wide frequency range over which the transmitter is sweeping.

4.2.4.2.6 - XPR long range relative positioning system:

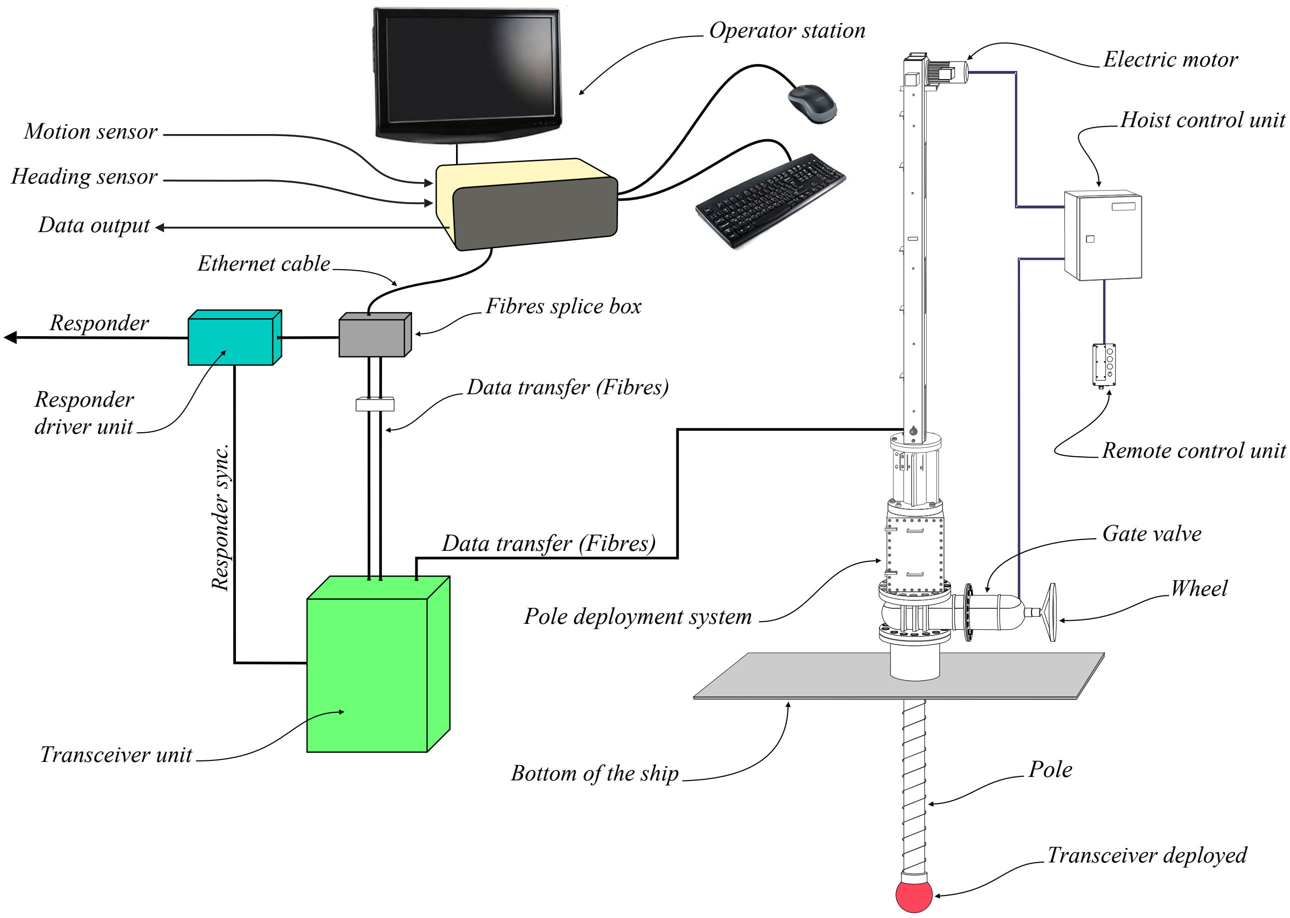
The XPR is a microwave-based solution for long-range relative positioning, that is also developed by Kongsberg. This system that operates in the 9.2-9.3 GHz band can be used with all weather conditions.
The system does not use moving parts, and each sensor unit has an opening angle of 100°. Also, sensor units can be combined to create an operational area of up to 280°.
The system automatically performs a function check prior to operation. Also, the target selection is automatic, and the devices stores them and continuously monitors in all directions to mitigates false targets lock and provide a high-speed acquisition. Its operational range indicated is from 10 m to 5 km with an accuracy of 1 m.
This system is complementary to other Dynamic Positioning solutions, and is compatible with the Artemis Mk4, Mk 5, and Mk 6.



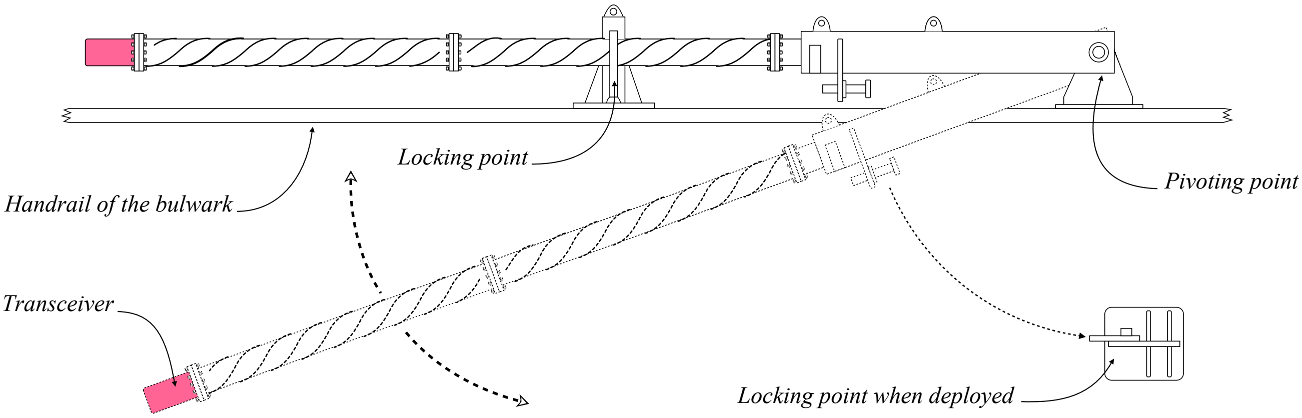
4.2.4.2.7 - Hydro acoustic systems:

A hydro-acoustic positioning system consists of both a transmitter (transducer) and a receiver (transponder). A signal (pulse) is sent from the transducer, and is aimed towards the seabed transponder. This pulse activates the transponder, which responds immediately to the vessel transducer. The transducer, with corresponding electronics, calculates an accurate position of the transponder relative to the vessel.

- SSBL (Super Short Base Line) & USBL (Ultra Short Base Line):
  They are hydroacoustic systems able to operate in shallow and deep waters to maximum ranges of 4000 metres to 10000 metres, depending on the performances of the equipment used.
  The calculation of positioning is based on the distance and vertical and horizontal angle measurements from a single multi-element transducer referenced to the system's heading unit, which is usually the gyrocompass.
  The transceiver of the boat is often deployed through the hull. As an example, the HIPAP system is an integrated solution designed by Kongsberg where this sensor is lowered several meters below the vessel hull through a gate valve until it is below the critical surface water layers as well as the noises generated by the propulsion devices of the vessel *(see the drawing below)*. Note that other manufacturers provide similar systems.

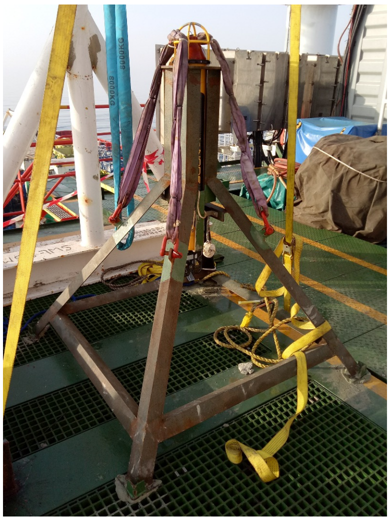


Deployment poles over the side may also be used. These systems are found with ships where through-hull deployment options are not available or practical. It is often the case when a diving operation is to be organized from a vessel of opportunity. With such systems, the metal pole is maintained along the side of the ship by a pivoting attach and two locking points; one when the mast is deployed in the water; and the other when it is secured along the bulwark. The deployment and recovery of the transceiver are usually made using a cable and a small winch.

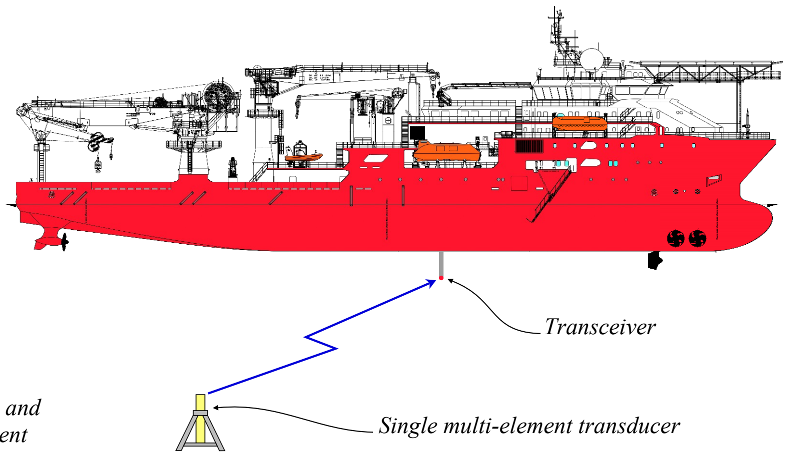


Note that strong currents can damage deployment poles, and for this reason, manufacturers give some maximum limits for their deployment. As an example, Sonardyne indicates 7 to 10 knots operational limit and 15 knots survival for transceivers deployed through the hull and 5 knots operational limits and 10 knots short term survival speed for devices deployed over the side.
The transceiver contains digital transmitters, pre-amplifiers and beam-forming electronics. It communicates with the Acoustic Positioning Operating System (APOS) via fibres optic cables.

The transponder is deployed on the seabed using a crane or a davit, and/or an underwater vehicle.



Transducer and its deployment rigging



In the dynamic positioning committee conference by Keith Vickery (Sonardyne) regarding acoustic positioning systems, it is said that the advantages of Ultra Short Baseline (USBL) positioning systems are the following:

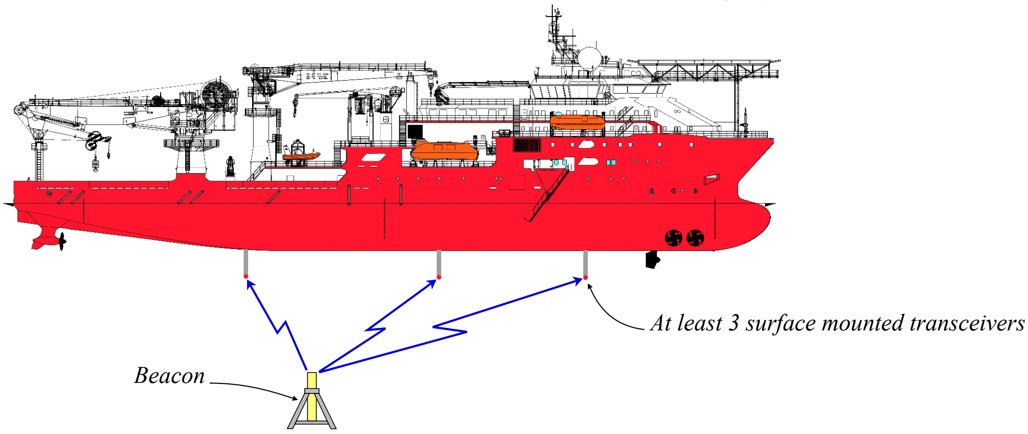
- Low system complexity makes USBL an easy tool to use.
- Ship based system – no need to deploy a transponder array on the seafloor.
- Only a single transceiver at the surface – one pole/deployment machine.
- Good range accuracy with time of flight systems.

The same author list the following disadvantages of Ultra Short Baseline (USBL) positioning systems:

- Detailed calibration of system required - usually not rigorously completed.
- Absolute position accuracy depends on additional sensors - ship's gyro and vertical reference unit.
- Minimal redundancy – only a few commercial systems offer an over-determined solution.
- Large transceiver/transducer gate valve or pole required with a high degree of repeatability of alignment.

- SBL (Short Base Line):

The Dynamic Positioning Committee says that “short baseline” systems derive a bearing to a beacon from multiple (at least 3 units) surface mounted transceivers. This bearing is derived from the detection of the relative “time of arrival” as a ping passes each of the transceivers. If a time of flight interrogation technique is used (Transponder or Responder) a range to that beacon will also be available from the SBL system.
A SBL system can work in pinger, responder or transponder mode. Any range and bearing (position) derived from a SBL system is with respect to the transceivers mounted on the vessel and as such a SBL system needs a Vertical Reference Unit (VRU), a Gyro, and possibly a surface navigation system to provide a position that is seafloor (earth) referenced.



The deployment and recovery of the transceivers and beacons are similar to the SSBL and USBL.

In the Dynamic Positioning Committee conference regarding acoustic positioning systems indicated previously, the advantages of Short Base Line (SBL) positioning systems are listed as follows:

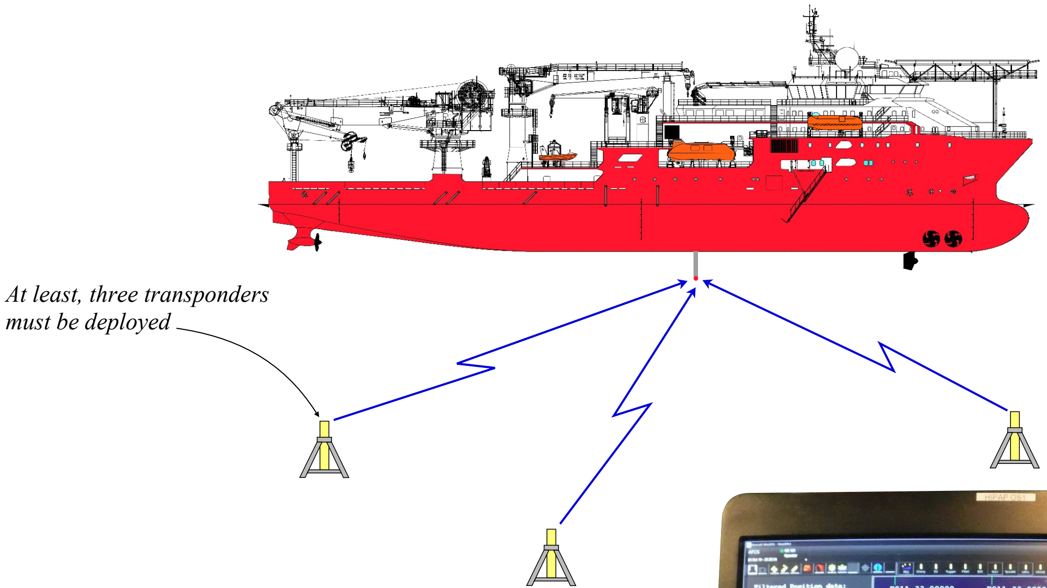
- Low system complexity makes SBL an easy tool to use.
- Good update rate when used with a pinger
- Good range accuracy with time of flight system.
- Spatial redundancy built in.
- Ship based system – no need to deploy transponders on the seafloor.
- Small transducers/gate values.

The disadvantages of Short Baseline (SBL) positioning systems are listed as follows by the same author:

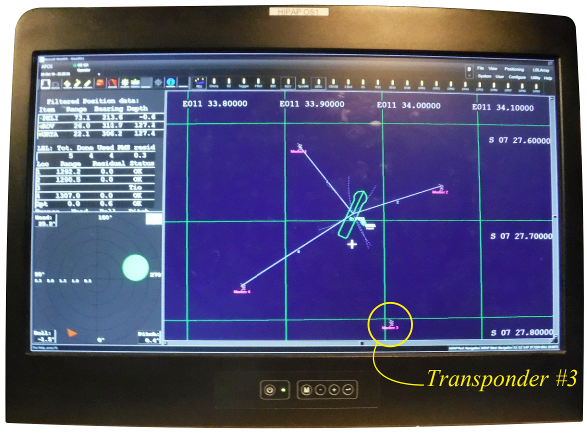
- System needs large baselines for accuracy in deep water (>30m).
- Very good dry dock/structure calibration required.
- Detailed offshore calibration of system required - usually not rigorously completed.
- Absolute position accuracy depends on additional sensors - ship's gyro and vertical reference unit.
- At least three transceiver deployment poles/machines needed.

- LBL (Long Base Line):

A Long Base Line system provides a position with respect to an area where three or more transponders that are located at known positions on the seabed are interrogated simultaneously by a transducer fitted to the Diving Support Vessel, so the position provided is with respect to seafloor coordinates. The distance between these transponders can be of several kilometers. The deployment of these devices is also similar to SSBL and USBL.



Note that it is usual to deploy more transponders than the minimum. That provides some redundancy in case of a failure that allows not to stop the operations.
It is the case in this photo, where the transponder #3 has ceased emitting. However, #1, #2, and #4 are still active, and the operations can be continued.



Using the same source as for the Ultra Short Base Line USBL and the Short Base Line (SBL), the advantages of Long Base Line positioning systems are listed as follows:

- Very good position accuracy independent of water depth.
- Observation redundancy.
- Can provide high relative accuracy positioning over large areas.
- Small transducer – only one deployment machine/pole.

According to the source above, the disadvantages of Long Baseline (LBL) positioning systems can be listed as follows:

- Complex system requiring expert operators.
- Large arrays of expensive equipment.
- Operational time consumed for deployment/recovery.
- Conventional systems require comprehensive calibration at each deployment.

- Combined systems:
DP specialists say that it is possible to combine the above systems to provide very reliable and redundant positions systems. Among the numerous possibilities, note the following combinations:

- Long + Ultra Short Base Line;
- Long + Short Base Line;
- Short + Ultra Short Baseline;
- Long + Short + Ultra Short Baseline.

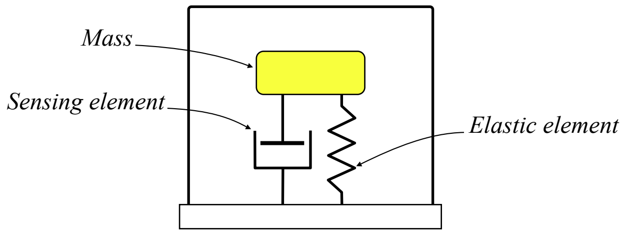
Also, multi-user systems are required where more than a single vessel is working within close proximity. The reason is that the acoustic positioning systems cannot provide sufficient channels within the standard bandwidth available to allow all vessels to position without interference between systems.

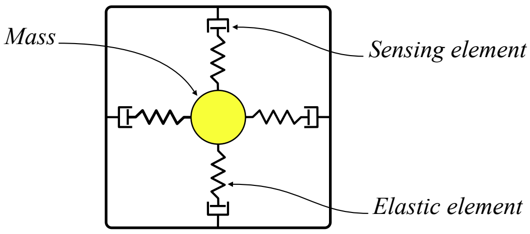
4.2.4.3 - Navigation systems and sensors

4.2.4.3.1 - Inertial navigation system (INS):

As already indicated in section 4.2.4.2.1, an "Inertial Navigation System" consists of accelerometers and gyroscopes, that compose the "Inertial Measurement Unit" (IMU), which provides acceleration and angular velocity measurements that are used by a computer to calculate the position of the vessel according to a known starting point. Note that the Inertial Measurement Unit (IMU) is sometimes called the Inertial Reference Unit (IRU).
This system that is usually designed to work with Global Navigation Satellite System (GNSS), combines three accelerometers and three gyroscopes

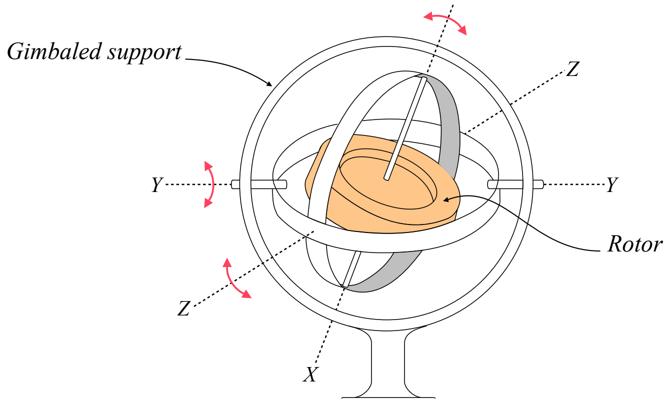
- Accelerometers are devices that measure acceleration, which is the rate of change of the velocity of an object. They provide their measures in metres per second squared (m/s^2), which is the official unit in the International System of Units (SI), or gravitational force equivalent, commonly called G-forces (g). A G-force is equivalent to 9.8 m/s^2. To provide a measure, the accelerometer converts the acceleration into a proportional electrical signal, usually voltage output. It is generally done using a small mass connected to elastic and sensing elements that measure the change of velocity in a given direction.





Accelerometers can measure acceleration on one, two, or three axes. Three-axis units are those used with boats. These devices can be analog or digital.

- A Gyroscope detects and measures the angular motion of an object relative to an inertial reference and has the orientation of its axis unaffected by tilting or rotation. So, it measures the absolute motion of an object without any external infrastructure or reference signal. These devices that were initially mechanical systems mounted on gimbaled supports *(see below)* are today replaced by electronic sensors.



4.2.4.3.2 - Heading Reference Sensors:
The heading is the direction to which a vessel is pointing. It is expressed as the angular distance relative to the north, which is usually expressed in degrees. The mechanical models of heading reference sensors are navigation gyrocompasses that looks like mechanical gyroscopes. A gyrocompass is a non-magnetic compass that is based on a fast-spinning disc and the rotation of the Earth to find geographical direction. Such devices have two significant advantages over magnetic compasses:

- They indicate the true north, which is not the case of magnetic compasses that are attracted by the magnetic north.
- They are unaffected by ferromagnetic materials, so they can be used in ships made of steel, which is the case of almost all working vessels.

However, these devices are gradually replaced by electronic systems using fibre optics and that do not use moving parts. IMCA M 252 says that these new models are considered more reliable, more accurate, and require less maintenance than the mechanical ones.

4.2.4.3.3 - Motion Reference Unit (MRU):
As already discussed with active heave compensation (AHC) systems, the Motion Reference Unit (MRU) is an inertial measurement unit with multi-axis motion sensors that actively measures all the movements of the vessel, and calculates the necessary counter-motion and controls of the system in real time. Note that the sensors of these devices are to be calibrated regularly for maintaining accurate operation.

4.2.4.3.4 - Anemometers
An anemometer is an instrument that measures wind speed, pressure, and direction. A lot of models exist that can be used for various applications. Among these systems, three types are commonly encountered on ships:

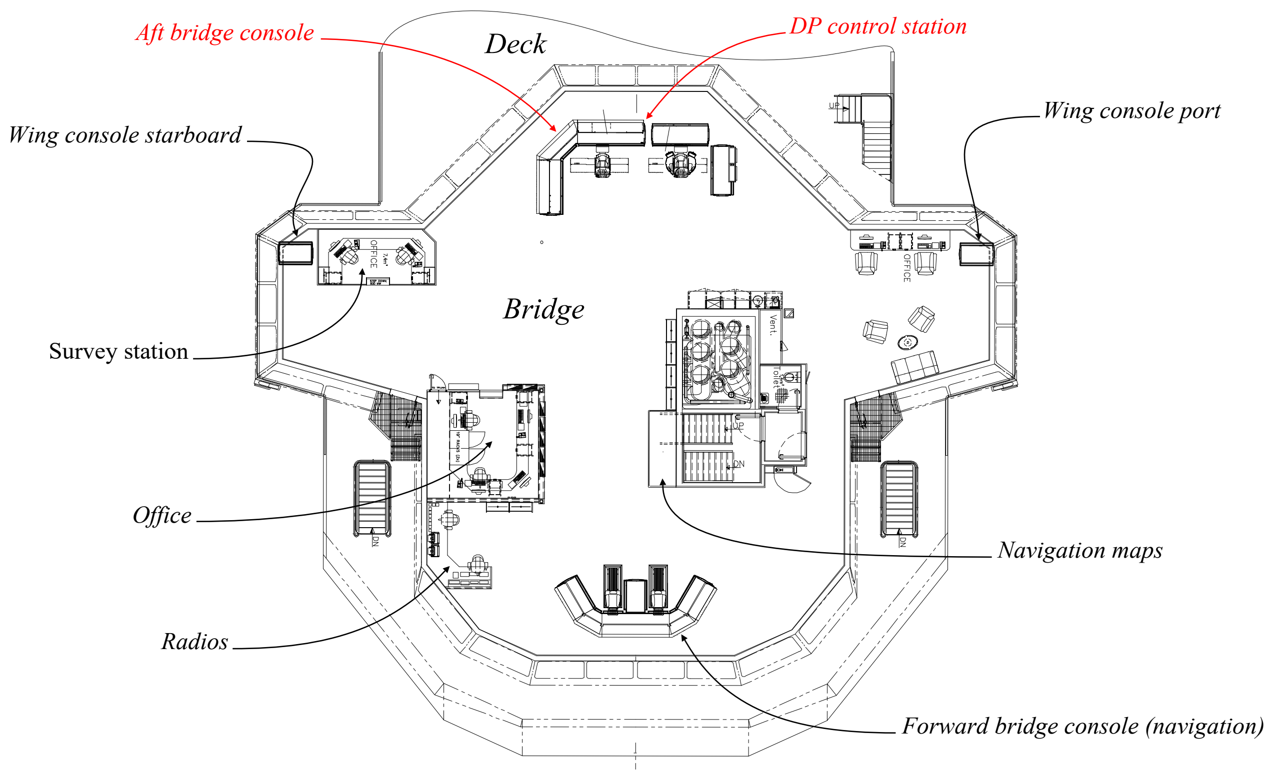
- Cup anemometers, that are four hemispherical cups mounted on horizontal arms, which are installed on a mast.
- Vane anemometers, that are propellers also installed on a mast.
- Ultrasonic anemometers use a transducer that emits ultrasounds that are speeded up by the wind and are then collected by a 2nd transducer. A computer measures the time between the two sensors to analyze the velocity at which the sound travels and calculate the wind speed. Also, because the speed of sound varies with temperature, such devices can be used as thermometers. The advantage of these systems is that they do not use mobile parts.

8.2.4.3.5 - Combined navigation and reference sensors:
As a result of the progress of electronics, manufacturers propose devices that combine several functions such as an example, Motion Reference Unit (MRU), plus heading and Global Navigation Satellite System (GNSS).

4.2.5 - Control systems

4.2.5.1 - General design of the Dynamic Positioning station

The Dynamic Positioning control system should be arranged in a control station where the operator has a good view of the vessel's exterior limits and the surrounding area. Usually the DP station is installed at the aft of the bridge, so the operator can see the deck and the main parts of the vessel. It is the case in the drawing below from UDS Lichtenstein.



The forward console is to be used when the vessel is in transit, and the aft navigation console is designed to manoeuvre the vessel and control her while she is in DP mode. Note that it is usually possible to start transiting from the aft console and then switch to the forward console.
Last generation DP vessels are provided with "wing consoles" on the port and starboard of the bridge that can be used for maneuvering the vessel in joystick mode for operations such as mooring alongside a vessel or a jetty.

On the vessel taken as example for this description, which is the Ultra Deep Solution Lichtenstein, the "forward console" is divided in six sections as follows:

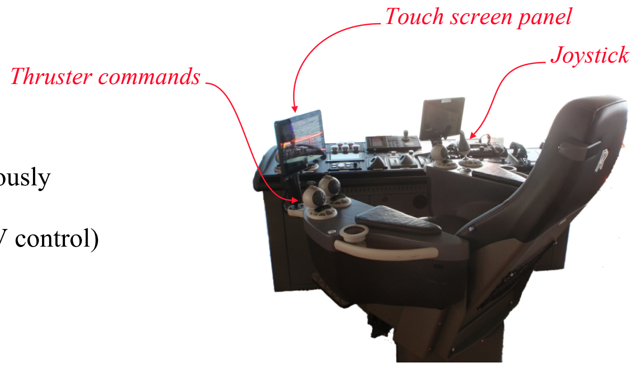
- Port section contains the following:
    - Water mist alarm panel & Emergency stop system.
    - Voyage Data Recorder (VDR) panel.
    - Bridge ventilation control panel.
    - Signal light control panel, searchlight control panel & ship telephone.
- The port corner section house the Electronic Chart Display Information System (ECDIS).
- Center section and center mid section contain the elements the most used during the navigation:
    - Gyro display (ECDIS) and rate of turn indicator.
    - Sound powered telephone and public address call station.
      whistle controller, Global Maritime Distress and Safety System (GMDSS) control panel with UHF (ultra high frequency and VHF (very high Frequency) transceivers.
    - Bridge watch call panel.
    - Manual thrusters levers and autopilot controllers and thruster emergency stop panel.
    - Automatic Identification System (AIS) transponder display (used to track the position of the vessel).
    - Speed log panel, magnetic compass display, X and S band radar displays.
- Starboard corner section houses the Close Circuit Television (CCTV) monitor.
- Starboard section contains:
    - Watertight door control panel.
    - Windless control panel.
    - Window wiper control panel.
    - UHF & VHF radios.
    - Call control units and survey monitors.

The aft console is organised in six sections as follows:

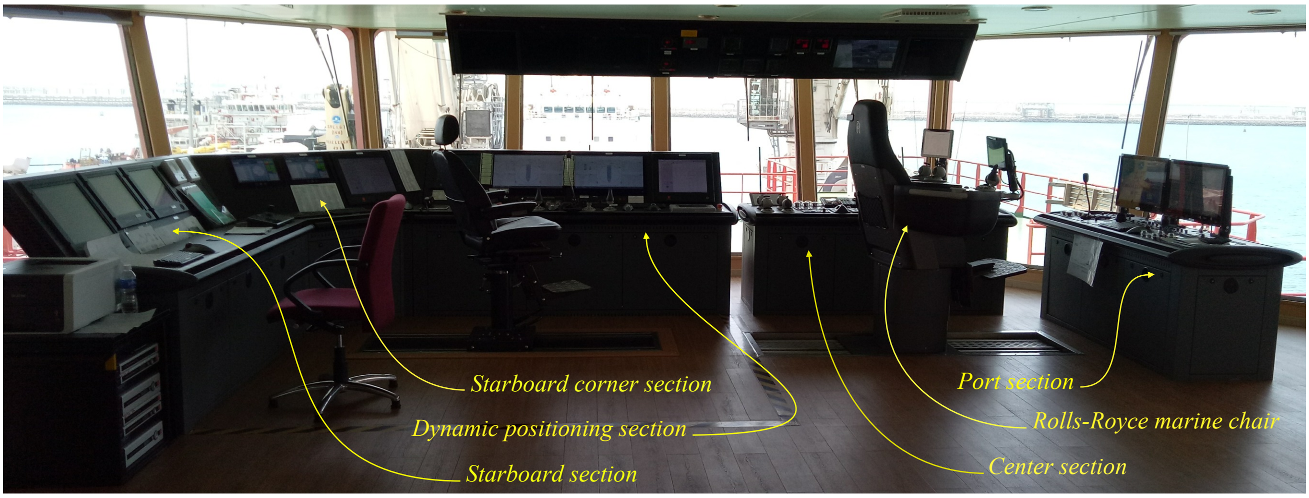
- Port section contains:
    - Public address system panel
    - General alarm, emergency stop panel, sprinkler control panel
    - Window wiper control
    - Joystick docking
    - DP chair manoeuvre mode selection panel.
- Center section includes:
    - Radar display selector switch
    - Telephone and sound powered telephone
    - Searchlight
    - Global Maritime Distress and Safety System (GMDSS) control panel with UHF (ultra high frequency and VHF (very high Frequency) transceivers
    - X and S band slave radar control.
    - Close Circuit Television (CCTV) monitor
    - DP system manoeuvre mode selection panel
    - Air whistle button

Hyperlink Tables of contents

- Rolls-Royce marine chair:
  - Thruster commands
  - PC touch screen panel
  - Joystick operation lever
- Dynamic positioning section contains:
  - The two DP operator stations described previously
  - Thruster emergency stop panel
  - Communication panel (to dive control & ROV control)
  - Port hydro-acoustics positioning control
  - CyScan laser control
  - UHF & VHF transceivers
- Starboard corner section
  - Starboard hydro-acoustics positioning control
  - DGPS 3 & 4 operating panel
- Starboard section contains:
  - CCTV monitor panel
  - Port & starboard bells phone station
  - Diver audio speaker
  - DGPS 1 & 2 display monitors
  - Computer loading station
- Wing consoles are installed port side and starboard side of the bridge they house:
  - A joystick docking point
  - A search light control panel
  - Manoeuvre mode selection panel
  - Bridge watch call reset button



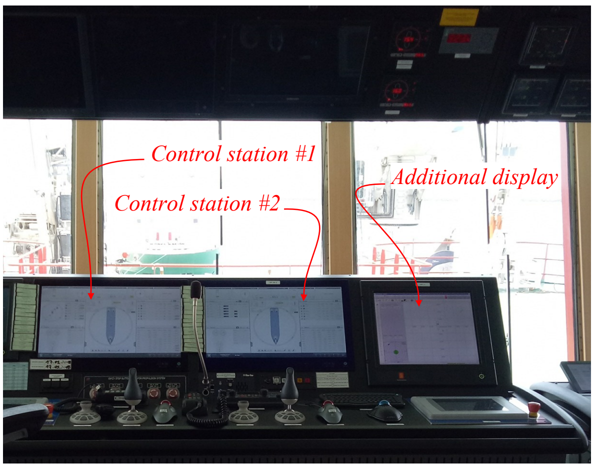
Rolls-Royce marine chair



The Circular 1580 from the IMO Marine Safety Committee (MSC.1-Circ.1580) says the following regarding ergonomics and safety devices that must be in place in the Dynamic Positioning station of diving support vessels:

- The DP control station should display information from the power system, thruster system, and DP control system to ensure that these systems are functioning correctly. Information necessary to safely operate the DP system should be visible at all times. Other information should be available upon the operator's request.
  Note that regarding this requirement, such information is usually displayed on the screens and the consoles in front of the operator as with the two examples below.

DP consoles Seven Pelican

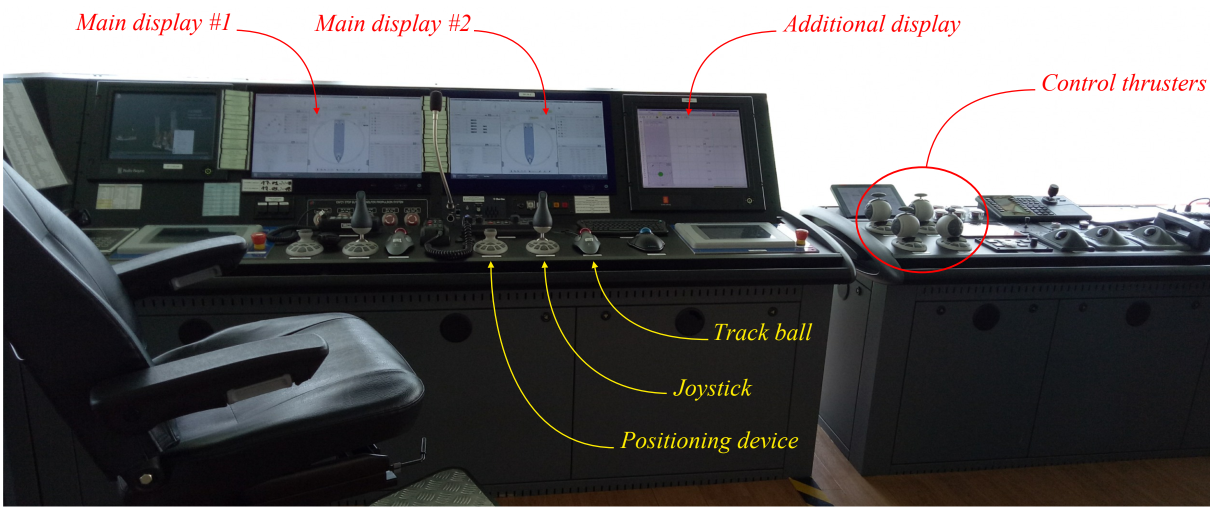


DP consoles UDS Lichtenstein

- Display systems and the DP control station, in particular, should be based on sound ergonomic principles that promote proper operation of the system.
  The DP control system should provide for easy accessibility of the control mode, i.e. manual joystick, or automatic DP control of thrusters, propellers, and rudders if part of the thruster system. The active control mode should be clearly displayed. Operator controls should be designed so that no single inadvertent act on the operator's panel can lead to a loss of position and/or heading.
  Note that it is the case of the two consoles displayed as an example on the previous page. Also, the control station must be appropriately illuminated to allow the operator to identify each control and command during the operations by night when the bridge cannot be lightened as the people on duty need to have a visual of the boat and her distance from a facility *(see the photo below)*.

- Alarms and warnings for failures in all systems interfaced to and/or controlled by the DP control system should be audible and visual. A record of their occurrence and of status changes should be provided together with any necessary explanations.
- The DP control system should prevent failures being transferred from one system to another. The redundant components should be so arranged that any failed component or components may be easily isolated so that the other component(s) can take over smoothly with no loss of position and/or heading.
- It should be possible to control the thrusters manually, by individual levers and by an independent joystick, in the event of failure of the DP control system. If an independent joystick is provided with sensor inputs, failure of the main DP control system should not affect the integrity of the inputs to the independent joystick.
  Note that it is the case in the photo below where manual commands are organized to allow the operator to intervene immediately. Also, in the system taken as an example, and as a summary of the elements indicated above, each main operator station gives the user the possibility of fully controlling the system, and consists of:
  - A main touch screen display
  - Input device(s)
  - Graphical User Interface (GUI) computer
  - A shared printer that is used by the system to print alarm reports and graphs when the system is active.

  The user interaction is done through a touch interface on the touch screen display 24” or 26” in combination with the input devices. An additional trackball is available as an option.
  The communication between the operator station and the control system is done through a combination of Control Area Network (CAN) “bus” and a redundant Ethernet connection *(see the definitions on the next page)*.
  The Main Display presents all necessary data for the user to operate the Dynamic Positioning (DP) system.
  Note that the joystick input device and the positioning device can be used to perform the most common operations in addition to control manually the vessel in case of a problem with the DP system.
  In addition, the operator can have manual control from the “Rolls Royce chair” (or similar) that is displayed on the previous page. However, note that this chair that allows controlling the vessel as an ROV is optional and not installed in most DP vessels.



Note the definitions below that are commonly used in computer architecture *(refer to the previous page)*:

- A “bus” is a communication system that transfers data between components inside a computer, or between computers.
- An “ethernet connection” is the most common way to set up a Local Area Network (LAN). Such a connection provides data transfer at acceptable rates over the network.

- Two Uninterruptible Power Supplies (UPS) should be provided for a class 2 equipment control system, and three for equipment class 3, to ensure that any power failure will not affect more than one computer system and its associated components. An Uninterruptible Power Supply (UPS) is an electrical apparatus that provides emergency power stored in batteries when the primary input power source fails, allowing sufficient time to switch-on the backup supply. Also, it acts as an electrical supply regulator, which avoids the computers and other sensitive equipment from being damaged by variations of voltage.
  The reference systems and sensors should be distributed on the UPSs in the same manner as the control systems they serve, so that any power failure will not cause loss of position keeping ability. An alarm should be initiated in case of loss of charge power. UPS battery capacity should provide a minimum of 30 minutes operation following a main supply failure.
  Note that the charge power for the UPSs supplying the main control system should originate from different power systems.

4.2.5.2 - Computer systems

Computers are the essential components of a Dynamic Positioning system, as they control the elements that allow analyzing a situation and provide an appropriate reaction to maintain the vessel in position.
Regarding the way such devices must be designed and organized for diving support vessels, IMO Maritime Safety Committee Circular 1580 (MSC.1/Circ.1580) says:

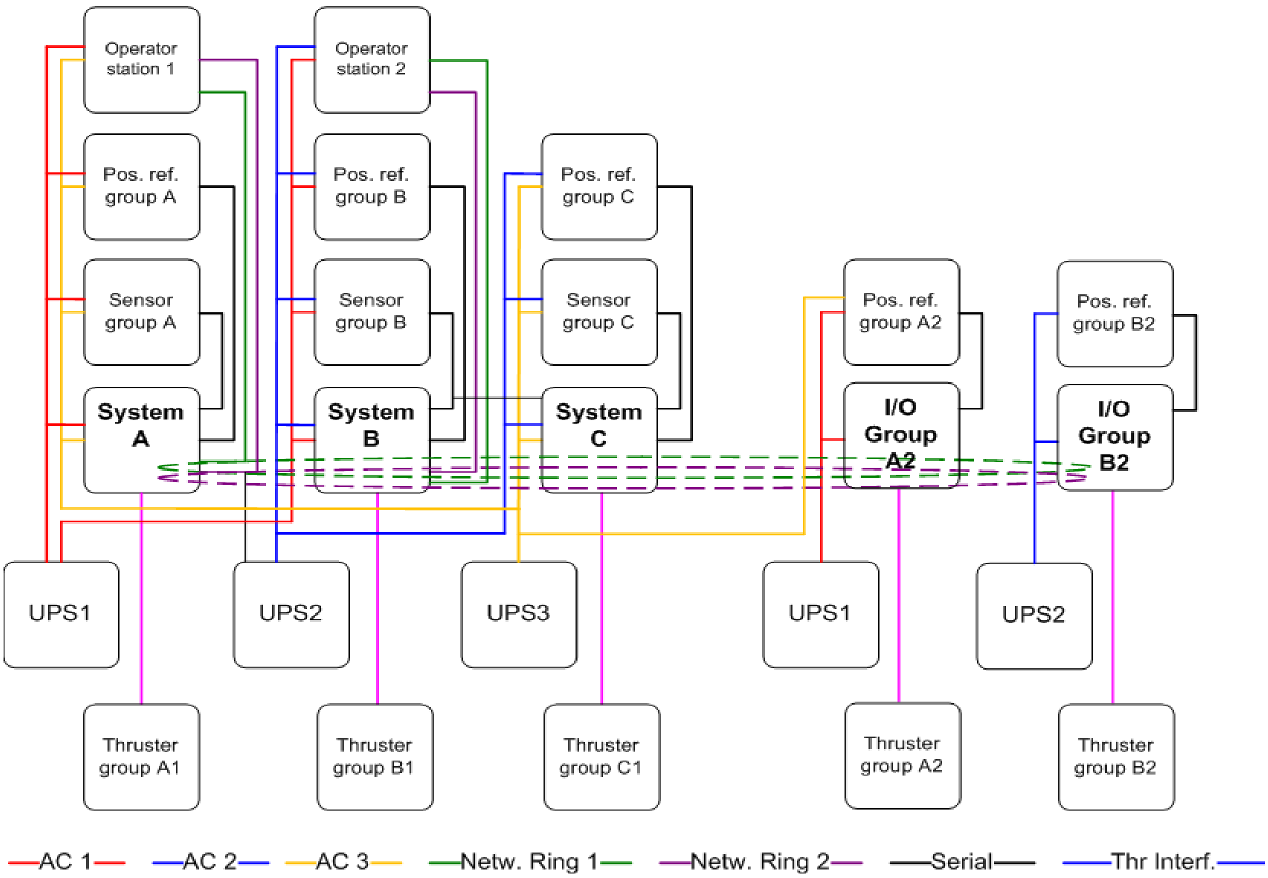
- For equipment class 2, the DP control system should consist of at least two computer systems so that, in case of any single failure, automatic position keeping ability will be maintained. Common facilities such as self-checking routines, alignment facilities, data transfer arrangements and plant interfaces should not be capable of causing failure of more than one computer system. An alarm should be initiated if any computer fails or is not ready to take control.
- The requirements for equipment class 3 are similar as above except that a separate backup DP control system should be arranged. This backup DP control system should be in a room separated by an A-60 class division (capable of resisting fire for 60 minutes) from the main DP control station.

- The DP control system should include a software function, normally known as "consequence analysis", which continuously verifies that the vessel will remain in position even if the worst-case failure occurs.
  This analysis should verify that the thrusters, propellers and rudders (if included under DP control) that remain in operation after the worst-case failure can generate the same resultant thruster force and moment as required before the failure. It should provide an alarm if the occurrence of a worst-case failure were to lead to a loss of position and/or heading due to insufficient thrust for the prevailing environmental conditions (e.g. wind, waves, current, etc.).
  For operations which will take a long time to safely terminate, the consequence analysis should include a function which simulates the remaining thrust and power after the worst-case failure, based on input of the environmental conditions.

- Redundant computer systems should be arranged with automatic transfer of control after a detected failure in one of the computer systems. The automatic transfer of control from one computer system to another should be smooth with no loss of position and/or heading.
  Also, during DP operation, the backup control system in the separate room should be continuously updated by input from at least one of the required sets of sensors, position reference system, thruster feedback, etc. and be ready to take over control.
  The switchover of control to the backup system should be manual, situated on the backup computer, and should not be affected by a failure of the main DP control system. Main and backup DP control systems should be so arranged that at least one system will be able to perform automatic position keeping after any single failure.
- Each DP computer system should be isolated from other on-board computer systems and communications systems to ensure the integrity of the DP system and command interfaces.
  This isolation may be effected via hardware and/or software systems and physical separation of cabling and communication lines.
  Robustness of the isolation should be verified by analysis and proven by testing. Specific safeguards should be implemented to ensure the integrity of the DP computer system and prevent the connection of unauthorized or unapproved devices or systems.

As an example of what is described above, the drawing below describes the communication between the different system parts of an existing DP2 vessel. Note that:

- The system is based on a triple controller system with a dual fibre-optic ring network.
- The interfaces to sensors and position reference systems, power system, and thruster system are split into groups.
- The interface to external systems (Input/Output) is separated from DP network to preserve the segregation between the systems.
- The DP cabinets, operator stations, sensors and position reference systems are powered through dedicated Uninterruptible Power Supply (UPS) systems.



4.2.6 - Safety rules for cabling and piping systems

Electrical and data cables, and also pipings are essential for the monitoring of the surrounding, and adequate response of the Dynamic Positioning System. For this reason, they should be designed with due regard to fire hazards and mechanical damages. Also, the following additional rules should be implemented for class 3 systems:

- Cables for redundant equipment or systems should not be routed together through the same compartments. Where this is unavoidable, such cables may run together in cable ducts of A-60 class, the termination of the ducts included, which are effectively protected from all fire hazards except that represented by the cables themselves. Cable connection boxes may not be provided within such ducts.
- Routing through separate compartments or in A-60 class ducts also applies to pipe systems.

4.2.7 - Voice communications and DP emergency alarm system

4.2.7.1 - Voice communications between the dive control and the DP station

Note that the way communications should be designed in the dive control is described in the document "Description of a saturation system".
IMCA says that voice communication by a priority system should be available between dive control and the DP control location. Open hands-free line with priority is a desirable facility. Such communications should be hard wired.
There should be a backup to this system which in most cases would be a common internal telephone network.
These communications should be checked during the initial DP stabilisation period. Also, marine radio communications can be used as a 2nd backup.

During the dive, the diving supervisor and the DP operator should inform each other about any change in operational circumstances, either existing or planned. The lists below gives an indication of the type of information which should be passed:

- Dive control to DP control:
  - Bell status, diver status, down-lines status.
  - Intention to use and use of water jetting equipment.
  - Possibility of divers, bell, or equipment blanking or moving acoustic reference signals.
  - Requests to move the vessel.
  - Intention to release high volume compressed air subsea.
  - Any situation which is unusual or may need a change to agreed procedures.
- DP control to dive control:
  - Intention to move vessel or change heading.
  - Changes in operational status affecting position control.
  - Any situation which is unusual or may need a change to agreed procedures.
  - Any forecast or actual significant changes in weather.
  - Vessel movements in the vicinity.
  - Intention to handle down-lines of any description, including repositioning taut wire weight.
  - Platform information relevant to operations.

4.2.7.2 - Diving Dynamic Positioning emergency alarm system

A system of lights and audible alarms, manually activated from, and repeated in the DP control room, should be provided in dive and ROV controls and working areas.

Also, the distinctive alarm for emergency alert should sound in the cabins of the master, the Offshore Construction Manager, the senior diving supervisor, and the client representative, in conjunction with a flashing red light.

A means of acknowledging and silencing these alarms should be available to allow for clear communications between the people involved in emergency actions.

The Dynamic positioning alarms of Diving Support Vessels can be classified as follows:

Colour	Status	Response to alert
Green	Normal operational status (green light). • Vessel under DP control and DP system operating normally with appropriate backup systems available. • Thruster power and total power consumption are optimal. • Vessel's indicated position and heading are within predetermined limits. • Negligible risk of collision exists from other vessels.	- Full DP diving operations can be undertaken.
Blue	Advisory status (blue light) *Note that this status is optional, and not available on a lot of vessels* • Approaching performance limits or reportable alarm status. • Operations may continue whilst risks are being assessed. • A failure has occurred that does not affect DP redundancy	- A risk assessment must be conducted to determine whether to continue, change position, or cease operations. - The diving supervisor should inform the divers and the team to prepare for a possible degraded status.
Yellow (flashing + buzzing)	Degraded status (yellow alert). • A failure in a sub-system has occurred leaving the DP system in an operational state such that an additional fault would cause a loss of position. • Vessel's position keeping performance is deteriorating and/or unstable or deviates beyond limits determined by risk analysis or HAZOP. • Risk of collision exists from another vessel. • Weather conditions are judged to be becoming unsuitable for DP diving. • Any other condition or circumstance which could reduce the status from normal.	- The diving supervisor should instruct the divers to suspend operations and move to a safe location. - The DPO, after consultation with the diving supervisor, should decide if any further action is necessary. - If the diving supervisor is unable to get clear advice from the DPO he will instruct divers to return to the bell.
Red (flashing + buzzing)	Emergency status (red alert). • System failure results in an inability to maintain position or heading control; • Any external condition exists, including imminent collision, preventing the vessel from maintaining position. • Onboard, this alert is often referred to as 'abandon ship'.	- The diving supervisor instructs the divers to return immediately to the basket and be recovered as soon as possible after due consideration of hazards involved in the recovery. - Key DP personnel should use all reasonable means available to limit the loss of position while the divers are being recovered.

These alarms must be tested before starting the diving operations. Note that sometimes the yellow emergency status light is amber or orange colour.

When supporting divers on DP, a clear procedure indicating the recommended responses to yellow and red alerts is required. The events that should trigger these alerts should be based upon the operating status levels reflecting the capability of the DP system to maintain the vessel on station within safe working limits.

Priorities should be clearly established for dealing with a DP emergency:
The authority of the master and diving superintendent are of fundamental importance at such times. They must cooperate closely on these priorities so that there is no room for doubt or dissension and so that the senior Dynamic Positioning Operator and diving supervisor on duty at the time of an emergency act with the same priorities without undue hesitation. For this reason, the following priorities should be considered:

- The safety of life is the first priority.
- The master has ultimate authority to assess and decide on courses of action in this respect. The advice of the diving superintendent should be taken into account.
- The safety of property is of lower priority. No effort should be made to safeguard property at the expense of safety to life, but the potential danger to life associated with certain threats to property should not be overlooked.
- The advice of the client's representative and offshore installation manager should be considered, where possible, with respect to the safety of offshore platforms and equipment.

4.3 - Dynamic positioning vessel documentation

The Dynamic Positioning Committee (DPC) says that, in addition to the IMO documentation requested to every ship, it is recommended that DP vessel owners and operators should maintain the documentation regarding the DP systems of their boats for the purposes listed below:

- Ensuring the safe and effective management of the vessel in DP.
- Ensuring the technical suitability of the vessel for each DP activity it is required to carry out.
- Determining the configuration for the critical activity mode of operation and the task appropriate mode.
- Understanding the vessel's station keeping capabilities following the worst case failure.
- Ensuring compliance with appropriate standards and guidelines.
- Providing training and familiarization material to vessel crews.

These documents are used by the National authorities maintaining registers of certificates and endorsements during the survey testing for the delivery of the Dynamic Positioning Acceptance Document (DPVAD). They should be kept on board and at the company office, and be updated. They may be in electronic or, hard copy format or, both.

4.3.1 - List of documents to be kept

No	*Document*	*Guidance from the Dynamic Positioning Committee*	*Additional explanations and guidelines*
1	DP system FMEA or FMECA	To be kept up to date, incorporating all modifications and additions since original study, if not in the document itself, then by other traceable means. All records to be on board.	Modifications and additions should be covered by a Management of change process that triggers updating the FMEA.
2	DP FMEA Proving Trials	To be conducted to prove initial DP FMEA and at other times to prove modifications and additions to the DP system. These trials should be repeated every five years. Findings and recommendations to be addressed in accordance with their criticality. All records to be on board.	Modifications and additions that should be proven by testing include all those that have direct effect or, potential to affect the performance or redundancy of the DP system. This will include protective, detection and monitoring functions
3	Annual DP Trials	To be conducted annually. Findings and recommendations to be addressed in accordance with their criticality. Previous trials reports and associated close out documentation to be on board.	The tests in the Annual DP Trials should be designed to prove system redundancy, as defined in the DP FMEA, system and equipment performance and functionality, to validate repairs and preventive maintenance, to protection and detection devices and their response so as to demonstrate that the vessel's DP system remains fit for purpose.
4	DP Capability Plots	Hard copy DP Capability Plots relevant to the vessel's areas of operations to be readily accessible to DPOs at the DP control location.	DP Capability Plots define by theoretical calculation the vessel's capability to maintain position in various environmental conditions. *More explanations are provided in the next point.*
5	DP Footprint Plots	Hard copy DP Footprint Plots to be taken by DP operators and kept on board. See Note 1 at end of table.	The plots are of the vessel's DP station keeping performance and limitations in various environmental conditions. *More explanations are provided in the next point.*
6	Service reports of the DP System	Complete history of service reports to be on board	There should be a process where the open items are highlighted, tracked and closed out.
7	Details of all DP related modifications and additions	Records of all DP related modifications and additions to be kept on board complete with interface and testing information.	Owners/ operators should keep adequate records and documentation relating to modifications and additions that could have an effect on the DP system, especially interfaces between equipment from different vendors. All modifications and additions should be subjected to FMEA type analysis and undergo Proving Trials type testing. New and modified software should be subjected to a thorough validation process, especially to avoid the acceptance of erroneous values.

No	Document	Guidance from the Dynamic Positioning Committee	Additional explanations and guidelines
8	Vessel audit reports and DP audits and inspection reports.	Complete history of all audit reports, DP audits and inspection reports, inc., findings and close outs to be on board.	There should be a process where the open items are highlighted, tracked and closed out.
9	DP Operations Manual	Vessel Specific DP Operations Manual , to be readily accessible at the DP control location and used by the DPOs as a reference for conducting DP operations.	It is recommended that owners/ operators develop a standardised table of contents for vessel specific DP Operations Manuals in their fleet. Modifications and amendments to the DP Operations Manual should be subject to Management of change processes, including changes to vessel specific checklists.
10	DP Incident Reports	Records of all DP station keeping and other DP related incidents to be kept on board, inc., investigation records and close outs.	All DP incidents should be investigated to an extent that reflects the potential consequences of the incident.
11	DP Mobilization/ DP Field Arrival/ Trials Procedures (Bridge and Engine Room)	Records of DP Mobilization Trials and DP Field Arrival Checklists to be kept on board for the period set by the owner/ operator and, where relating to a DP incident permanently stored in retrievable archives.	DP Trials and Checklists should be vessel specific and be developed from detailed information contained in the DP FMEA. They should confirm vessel performance, particularly following worst case failure, and that the vessel's DP system is set up properly and provides the required level of redundancy.
12	DP Location and Watchkeeping checklists (Bridge and Engine Room)	Records of all DP Location and Watchkeeping checklists to be kept on board for the period set by the owner/ operator and, where relating to a DP incident, permanently stored in retrievable archives	As above
13	DP related drills and emergency response drills	Records of DP related drills and emergency response drills to be kept on board in retrievable archives.	DP drills can be developed from fault and single point failure scenarios addressed in the vessel's DP FMEA. The drills should also cover extreme events that are outside the scope of the DP FMEA. The outcomes from these drills should be used in the development of DP emergency response procedures and used as training material for DP personnel. These records may be used in a cycle of continuous improvement.
14	DP fault log	Records of all faults related to the DP system to be kept on board permanently in retrievable archives.	DP faults should be recorded as soon as possible after they are discovered and action/ investigation taken appropriate to the potential consequences of the fault on the vessel's station keeping ability.
15	DP data logging	Where the vessel has DP data logging facilities electronic records should be kept on board for the period set by the owner/ operator and, where relating to a DP incident, permanently stored in retrievable archives.	DP data loggers perform an important function in helping to determine root causes of faults or failures. It is recommended that a DP data logging function is included as part of the DP system design specifications. DP data loggers should be commissioned and operational before DP system Customer Acceptance Trials (CAT) are carried out. The DP data logger should be incorporated in the Critical Activity Mode of Operation/ Task Appropriate Mode (CAMO/TAM) and running at all times when in DP. If not, this should trigger an Advisory condition. There should be specific procedures for the operation and analysis of output from the DP data logger. This should include clear instructions on how and where the records are kept. Retention of logging data should not be limited by time.

No	Document	Guidance from the Dynamic Positioning Committee	Additional explanations and guidelines
16	DP alarm printer readouts	Hard copy records of the DP alarm printer readout to be kept on board for the period set by the owner/ operator and, where relating to a DP incident, permanently stored in retrievable Archives.	Owners/operators frequently require DP alarm printer readouts to be kept for the duration of each well and then destroyed, unless relating to a DP incident or contractual dispute.
17	DP familiarisation and competency records	All records relating to vessel specific DP familiarisation and competency for DPOs, engineers and electricians to be kept on board permanently in retrievable archives.	Owners/ operators should implement an in-house DP competency assurance process for key DP personnel which is structured, systematic and progressive. It should be noted that Dynamic Positioning Officer (DPO) certification is only one element in the competency assurance process.
18	Résumés and vessel specific work records of all key DP personnel	Resumes of all key DP personnel, copies of certification and qualifications, records of DP watchkeeping hours to be maintained on board. Original DPO certificates and DP Log Books to be held by the DPOs onboard the vessel.	

4.3.2 - Definitions

4.3.2.1 - Dynamic Positioning FMEA

Failure Mode Effect Analysis (FMEA) is a document that provides a systematic analysis of systems and sub-systems to a level of detail that identifies all potential failure modes down to the appropriate sub-system level and their consequences. The difference between FMEA and FMECA (Failure Mode Effect Critically Analysis) is in the method of analysis used: FMEA is based on the evaluation of a Risk Priority Number based on severity, likelihood, and detection, where FMECA calculates the criticality of each potential failure *(more explanations regarding this point are given in point 4.3 in this book)*.

The Dynamic Positioning Committee says that the DP FMEA is the most important technical document in the list of required documents and is required by IMO Maritime Safety Committee circulars 645 (1994) and 1580 (2017).

In addition to complying with the IMO Guidelines and the relevant DP rules of the vessel's classification society the DP FMEA should achieve the standards of detail and analysis contained in the following industry guidance:

- IMCA M166 "Guidance on Failure Modes and Effects Analysis"
- IMCA M178 "FMEA Management Guide"
- MCA M04/04 2004 "Methods of Establishing the Safety and Reliability of DP Systems"

Note that FMEAs are a requirement to obtain DP Class 2 and 3 notation *(see in point 8.2.3)*.

Also, note the following definitions that are linked to FMEA:

- *FMEA proving trials* means the test program for verifying the FMEA
- *Hidden failure* means a failure that is not immediately evident to operations or maintenance personnel and has the potential for failure of equipment to perform an on-demand function, such as protective functions in power plants and switchboards, standby equipment, backup power supplies or lack of capacity or performance.
- *Worst Case Failure (WCF)* is the identified single failure mode in the DP system resulting in maximum effect on DP capability as determined through FMEA study.
- *Worst Case Failure Design Intent (WCFDI)* is the single failure with the maximum consequences that has been the basis of the design and operational conditions. This usually relates to a number of thrusters and generators that can simultaneously fail.
- *Redundancy Concept* is the means by which the Worst Case Failure Design Intent is assured.
- *Critical Activity Mode* is the configuration that the vessel's DP system should be set up and operated in so as to deliver the intent of the vessel's DP class notation. The objective is that no single failure should result in exceeding the worst case failure. Each DP vessel has only one critical activity mode which is unique to that vessel.
- *Thruster and generator operating strategy (TAGOS)* is a document that provides informed guidance, usually derived from a review of the FMEA and if necessary, validation from personnel knowledgeable about vessel specific information, on appropriate configurations of thrusters, generators and power distribution, and associated constraints, so as to enable correct choices to be made to provide optimum level of redundancy.

Key DP personnel, including the vessel Master, DPOs, Engineers and Electricians should have a detailed knowledge of the DP FMEA and should use the information provided to be fully informed about the capabilities and limitations of the vessel's DP system.

4.3.2.2 - Dynamic Positioning capability plots

The Dynamic Positioning Committee says that these theoretical plots are calculated from detailed information of the vessel's hull and superstructure form and available thruster power.
The calculations should use environmental data (sea state, wind and current) appropriate to the area in which the DP vessel is to operate. Also, they should show the limiting wind speed 360 degree envelopes for the scenarios below, where each point on the envelope represents the wind speed at which it is calculated that the vessel will be unable to maintain position in DP.

DP Capability Plots should include the following scenarios at current speeds of 0 kts, 1 kt and 2 kts, or at other current speeds that are representative of the location in which the DP vessel is to operate:

- Fully intact power generation and thrusters.
- Loss of most effective thruster(s).
- Following the worst case failure.

Note the following:

- The DP Capability Plots should be provided in a format that is intuitive to the user on board.
- The guidance IMCA M 140 "Specification for DP Capability Plots" is recommended for these calculations.

4.3.2.3 - Dynamic Positioning footprint plots

In addition to what is said above, the Dynamic Positioning Committee says that DP Footprint Plots should also be produced on board.
DP Footprint Plots are not theoretical. They are actual measurements of the vessel's DP station keeping performance in the actual environmental conditions and thruster configuration at the time the plot was taken. DP Footprint Plots should be taken whenever opportunities arise, such as during standby periods, weather downtime or on arrival at the field.
Plots should be taken for the thruster configurations used in the DP Capability Plots, i.e. fully intact, loss of most effective thruster(s) and after worst case failure.

Some DP systems have a software application that produces DP Footprint Plots electronically. DPOs can also produce DP Footprint Plots by manual methods using a plotting sheet.

The Dynamic Positioning Committee says that DP Footprint Plots serve two main purposes.

1. They provide a scatter plot of vessel positions at regular intervals around the required set position (this shows accuracy of station keeping)
2. They also provide comparison points on the limiting wind speed envelope given in the theoretical DP Capability Plots (this shows wind speeds at which it was seen that the vessel was unable to maintain position, thus validating or contradicting the theoretical DP Capability Plots for the various thruster configurations).

DP Foot print Plots can also be used for other purposes, including learning and familiarisation opportunities for DPOs and in providing snapshots of vessel station keeping behaviour for specific locations and activities.
In addition, theoretical DP capability plots and DP footprint plots combine together to enhance knowledge and understanding of the vessel's DP station keeping ability.

Note the following:

DP Footprint Plots originated in harsh weather regions, such as in the North Sea.
The plots are used to gain a better understanding of the vessel's actual station keeping performance and limitations in intact and, in various degraded thruster configurations, including worst case failure, whilst the vessel is being subjected to real environmental forces.

4.3.2.4 - Critical activity mode of operation

Critical Activity Mode of Operation (CAMO) is generally a tabulated presentation of how to configure the vessel's DP system, including power generation and distribution, propulsion and position reference systems, so that the DP system, as a whole, delivers the intent of the vessel's DP class notation. The CAMO table also sets out the operator actions should a required configuration not be met.

4.3.2.5 - Activity specific operating guidelines

Activity Specific Operating Guidelines (ASOG) are generally presented in tabulated format and set out the operational, environmental and equipment performance limits considered necessary for safe DP operations while carrying out a specific activity. The table also sets out various levels of operator action as these limits are approached or exceeded.
The ASOG will vary depending on the activity and are unique to that activity.

4.3.2.6 - Task appropriate mode

Task Appropriate Mode (TAM) is a risk based mode. Task Appropriate Mode is the configuration that the vessel's DP system may be set up and operated in, accepting that a single failure could result in exceeding the worst case failure and could result in blackout or loss of position.
This is a choice that is consciously made.
This mode may be appropriate in situations where it is determined that the risks associated with a loss of position are low and, where the time to terminate is low.

4.3.3 - Survey testing and dynamic positioning acceptance document (DPVAD) - (IMO-MSC.1/Circ.1580)

4.3.3.1 - Surveys and testing

IMO says that each DP vessel should be subject to the surveys and testing specified below:

- An initial survey which should include a complete survey of the DP system and FMEA proving trials for DP classes 2 and 3 to ensure full compliance with the applicable parts of the guidelines MSC.1/Circ.1580. Furthermore it should include a complete test of all systems and components and the ability to keep position after single failures associated with the assigned equipment class. The type of tests carried out and results should be recorded and kept on board.
- A periodical testing at intervals not exceeding five years to ensure full compliance with the applicable parts of the guidelines. The type of tests carried out and results should be recorded and kept on board.
- An annual survey should be carried out within three months before or after each anniversary date of the Dynamic Positioning Verification Acceptance Document 1 . The annual survey should ensure that the DP system has been maintained in accordance with applicable parts of the Guidelines and is in good working order. The annual test of all important systems and components should be carried out to document the ability of the DP vessel to keep position after single failures associated with the assigned equipment class and validate the FMEA and operations manual. The type of tests carried out and results should be recorded and kept on board.
- A survey, either general or partial according to circumstances, should be carried out every time a defect is discovered and corrected or an accident occurs which affects the safety of the DP vessel, or whenever any significant repairs or alterations are made. After such a survey, necessary tests should be carried out to demonstrate full compliance with the applicable provisions of the guidelines MSC.1/Circ.1580. The type of tests carried out and results should be recorded and kept on board.
- As indicated in the previous points an FMEA should be carried out for equipment classes 2 and 3.

These surveys and tests should be witnessed by officers of the Administration. The Administration may, however, entrust the surveys and testing either to surveyors nominated for the purpose or to organizations recognized by it.
In every case, the Administration concerned should guarantee the completeness and efficiency of the surveys and testing.
The Administration may entrust the company of the vessel to carry out annual and minor repair surveys according to a test programme accepted by the Administration.
After any survey and testing has been completed, no significant change should be made to the DP system without the sanction of the Administration, except the direct replacement of equipment and fittings for the purpose of repair or maintenance.
Note: Administration means the National authorities maintaining registers of certificates and endorsements.

4.3.3.2 - Dynamic Positioning Verification Acceptance Document (DPVAD)

The Dynamic Positioning Verification Acceptance Document (DPVAD) is issued by or on behalf of the administration. The document should be drawn up in the official language of the issuing country and in the form provided with the guidelines MSC.1/Circ.1580.
If the language used is neither English nor French, the text should include a translation into one of these languages. This document is valid for a period not exceeding five years, or for a period specified by the Administration.

The DPVAD should cease to be valid if significant alterations have been made in the DP system equipment, fittings, arrangements, etc. specified in the guidelines MSC.1/Circ.1580, without the sanction of the Administration, except the direct replacement of such equipment or fittings for the purpose of repair or maintenance.

It also should cease to be valid upon transfer of such a vessel to the flag of another country.

Also, the privileges of the DPVAD may not be claimed in favour of any DP vessel unless the DPVAD is valid.

The results of the DPVAD tests should be readily available on board for reference.

4.3.4 - Training and competencies of DP personnel

4.3.4.1 - IMO Maritime Safety Committee - Circulars 1580 and 738

IMO Maritime Safety Committee - Circular 1580 says:
Personnel engaged in operating a DP system should have received relevant training and practical experience in accordance with the provisions of the 1978 STCW Convention, as amended, the STCW Code, as amended, and the Guidelines for Dynamic Positioning System (DP) Operator Training (MSC/Circ.738, as amended).

IMO Maritime Safety Committee - Circular 738 says:
The Committee, at its ninety-seventh session (21 to 25 November 2016), noted information by IMCA that the Guidelines had been updated to ensure conformance with current best practice and reissued as IMCA M 117 Rev.2, which is annexed to document MSC 97/INF.9. The Committee also noted that there have been no changes to the core content of the Guidelines, and may be amended by IMCA from time to time in the future.
The Committee noted that the above-mentioned IMCA publication identifies training programs, levels of competency, and experience for the safe operation of DP vessels, the most recent one of which is available from the International Marine Contractors' Association (IMCA).

4.3.4.2 - Competencies of Key personnel

As indicated above, IMCA M 117 "The Training and Experience of Key DP Personnel" is recognized suitable for the training, competence, and experience required of all key DP personnel on dynamically positioned (DP) vessels by IMO. This guidance says the following regarding DP competencies of key personnel:

- *Master*:
  The master should understand the need for and implement good communications between the bridge and engine control room and have a comprehensive knowledge of the vessel's operations manuals including the FMEA and related FMEA trials as currently updated.
  Additionally, they should be competent to conduct annual trials, lead DP drills, direct the training of new and existing DP personnel.
  If it is a requirement for them to operate the DP control system, they should have greater or equivalent DP operational knowledge to the senior DPO.

- *Senior Dynamic Positioning Operator (SDPO)*:
  The person fulfilling the role of the Senior Dynamic Positioning Operator (SDPO) is the lead watch-keeper with responsibility for the navigational safety and control of the DP system necessary to achieve the effective and efficient progression of the industrial mission of the vessel whilst on watch.
  The SDPO should hold a formal qualification as a deck officer in accordance with current Standards of Training, Certification and Watchkeeping for Seafarers (STCW) Convention standard or flag state equivalent, and also hold a valid, industry recognised, DP operator certificate.
  The SDPO should satisfy vessel owner/operator requirements to undertake the role of lead Dynamic Positioning watch-keeper and should have been assessed by the master as having the experience, knowledge, and competence to take sole charge of a Dynamic Positioning watch.
  They should also be capable of providing supervision to other Dynamic Positioning Operators, for any DP operation that the particular vessel may be engaged in.

- *Dynamic Positioning Operator (DPO)*:
  The person fulfilling the role of Dynamic Positioning Operator is the second person on the watch and is therefore not in sole charge of the watch. Their required experience and knowledge depends on the type of DP vessel and the complexity of the current industrial mission of the vessel.
  Vessel owners/operators should consider the critical nature of the industrial mission, the Activity Specific Operating Guidelines (ASOG) or its equivalent and take a risk based approach to determine the level of experience, knowledge and competence required by the DPO. The person fulfilling the role of SDPO should be in the same work space and maintain continuous oversight of the activities of the DPO.
  Vessel owners/operators should take every opportunity to train DPOs to be capable of taking charge of the DP watch during DP operations.
  Two recognised categories of DPO can fulfil the role of the second person on the DP watch.
    - Certificated DPO, who is a DP operator who has successfully completed an industry recognised DPO training scheme and is in possession of a valid DP operator certificate. Although competent to be part of a DP watch a DPO acting in this role might not yet be expected to take sole charge of the DP watch.
    - A junior DPO who is a person participating in an industry recognised DPO training scheme managed and/or certified by a recognised industry body and not in possession of a valid DP operator certificate. The junior DPO is to be suitably supervised while on watch by a certificated DPO.

- *Chief engineer*:
  The chief engineer is responsible for ensuring the mechanical and electrical systems of the vessel are operated and maintained in a safe and efficient manner.
  The chief engineer should hold a professional qualification as chief engineer to current Standards of Training, Certification and Watchkeeping (STCW) convention standard or flag state equivalent, and have completed the manufacturer/supplier approved operator training course on the integrated DP/power management control system.
  In addition, if the vessel has a high voltage system, they should hold a certificate for operating an electrical high voltage system and have had instruction on the high voltage system installed.
  The chief engineer should have appropriate experience, knowledge and competence to take charge of an engine room watch during DP operations. He should understand the need for and implement good communications between the bridge and engine control room and have a comprehensive knowledge of the vessels operations manuals including the FMEA and related FMEA trials as currently updated.

- *Senior Engine Room Watch-keeper:*
  This person responsible for the safe and efficient running of mechanical and electrical systems whilst on watch.
  The senior engine room watch-keeper holds a formal, appropriate and current qualification to an approved Standards of Training, Certification and Watchkeeping (STCW) Convention standard or flag state equivalent, and have completed the manufacturer/supplier approved training course on any integrated DP/power management control system.
  In addition, if the vessel has a high voltage system, they should hold a certificate for operating an electrical high voltage system and have had instruction on the high voltage system installed.
  The Senior engine room watch-keeper should have sufficient knowledge, experience and competence to take charge of a watch in the engine control room (ECR) or equivalent during DP operations, and understand the operational requirements of the vessel and the consequences of various failures in equipment of importance to DP operations

4.4 - Prepare for diving operations from Dynamic Positioning vessels

4.4.1 - Prepare the umbilicals

4.4.1.1 - Hazard linked to active propellers and sea-chests

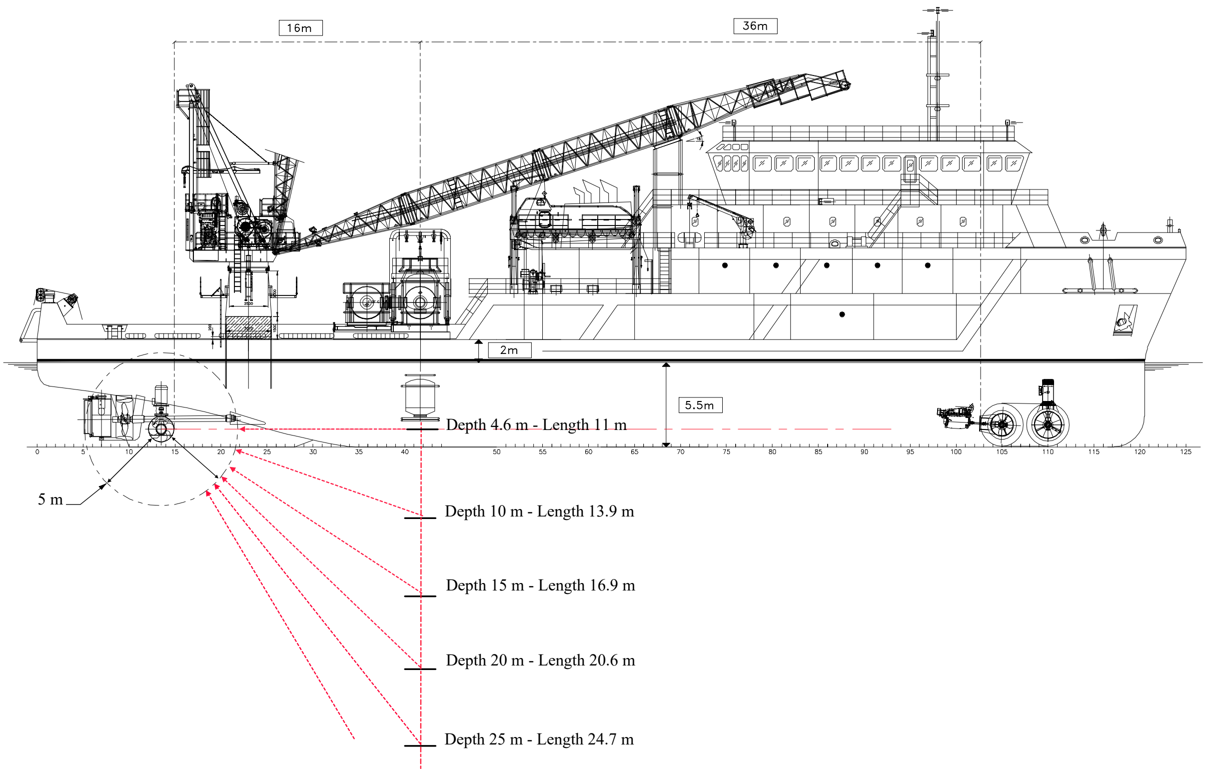
The thrusters and propellers used by Diving Support Vessels and described in point 8.2.3.1 can have propellers up to 5 metres diameter. As they are always active, these propellers are deadly traps for the divers. Also, even though it is common to protect the propellers of tunnel thrusters by grids mounted at the entrance of the tunnel to prevent damage to such equipment by large items or debris. It must be noted that specialists say that these guards are not to be considered capable of protecting divers.
Note that surface-orientated divers working close to the surface are vulnerable to such hazards as the divers can be at the direct proximity of such thrusters. It is less the case with surface-supplied and saturation dives sufficiently deep to be away from these dangers. Note that in the case of shallow dives on the bottom of the sea, the proximity of the propellers with the bottom may impact the divers' visibility.

Inlet sea-chests are usually protected by grids. However some of them have sufficiently strong suction to catch a diver moving at their direct proximity. Such hazards do not usually affect saturation divers as they do not intervene on the hull, and are deployed only when the bell has arrived at the working depth. However, they may affect a surface orientated diver working near the surface or sent to assist the recovery of the saturation diving bell during an emergency.

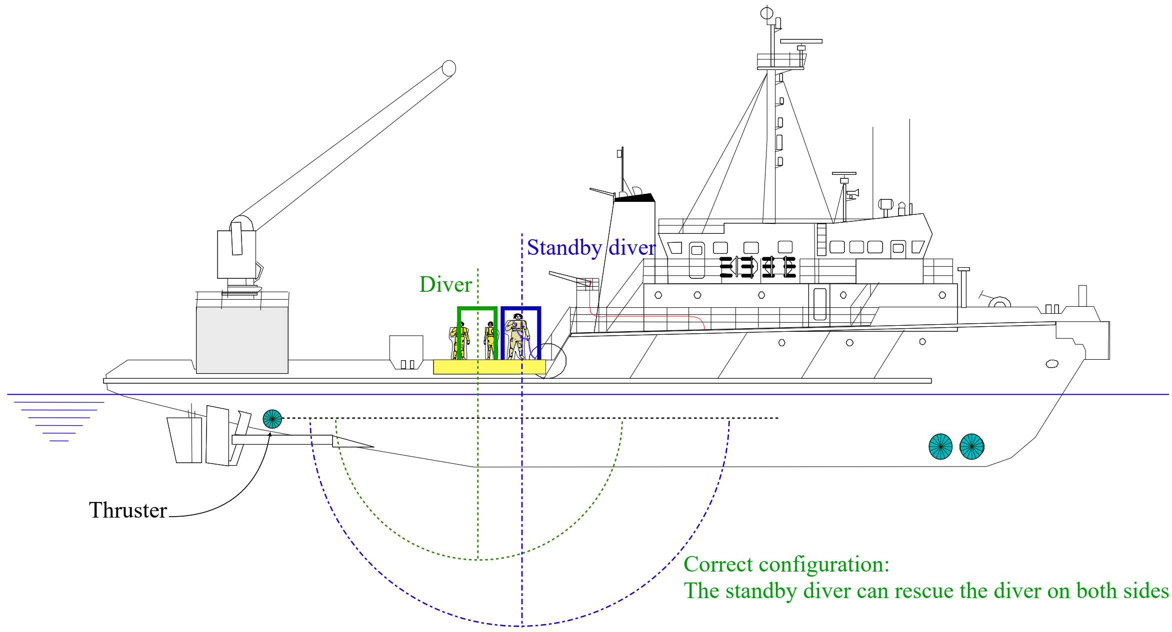
4.4.1.2 - Methods used to protect the divers from active propellers and sea-chests

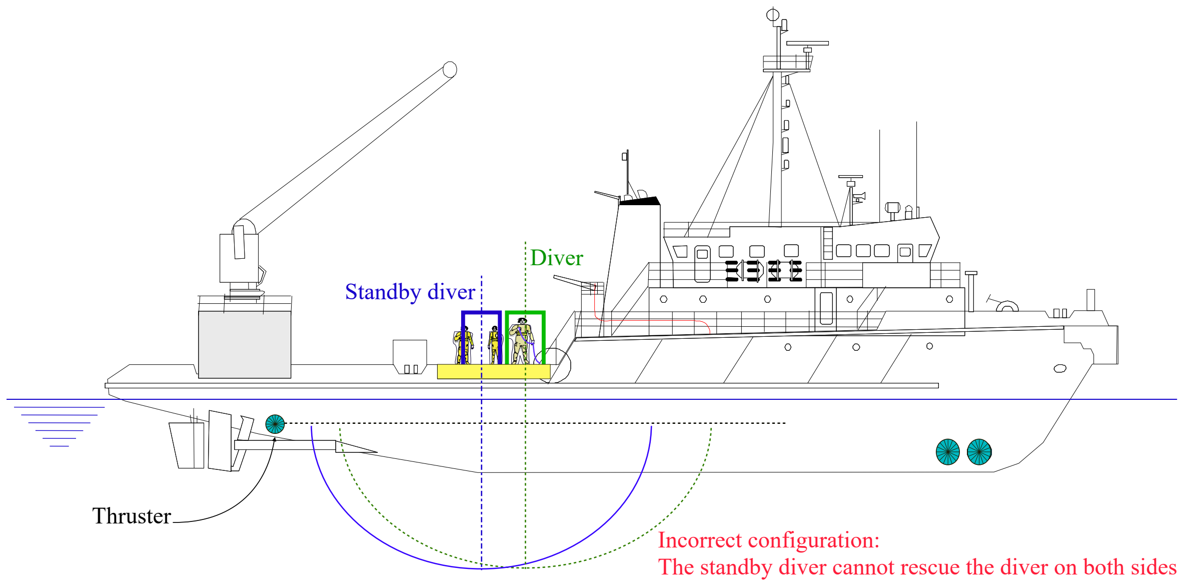
The method to apply consists of organizing the umbilicals and the launching station in such a way that the divers are not in the direct vicinity or contact with the hazards that have been identified:

- The 1st step consists of establishing a precise drawing of the boat where the propellers, thrusters, and sea-chests are identified and precisely located. Such drawings that are based on those used for the construction of the vessel are usually available in any ship. However, they are generally under DWG format or similar, and it may be necessary to clear them from unnecessary details.
- The second step consists in establishing the restrictions:
  - The deployed umbilicals should be restricted and secured, so the divers and bellman are physically prevented from coming into contact with the hazards that have been identified.
  - IMCA D 010 says that a thruster configuration diagram showing the deployment device at various depths, at 10 metre increments, and distance to the nearest thruster should be established. The distance will need to be measured from the centre line of the deployment device to the outer moving part of the thruster “envelope”. IMCA also says that when producing the diagram, due consideration should be given to how and where the bellman’s umbilical is deployed from and to where it is secured.
  - Most organizations say that the safe umbilical lengths for the working divers are the measurement procedure recommended above, minus 5 metres. Note that for the rescue diver, the safe umbilical distance is calculated using the procedure above, minus 3 m instead of 5 metres. So the rescue diver is 2 m closer to the danger than the diver. *The methods for calculating these distances are explained in the next point.*



- When the deployment of the standby diver and the working diver are from different locations, the proximity of hazards to these locations must be taken into account when calculating the umbilical lengths. It must be noted that such considerations may result in additional restrictions on the length of the working diver's umbilical.
- The standby diver basket must be selected to allow for a safe intervention of the standby diver in any situation. A wrong selection of this basket could make this intervention impossible or oblige to additional restrictions of the working diver's umbilical. Before starting the dives, drawings and calculations must be done to select the proper basket. See the example below with the diver's umbilical range in green and the standby diver in blue.



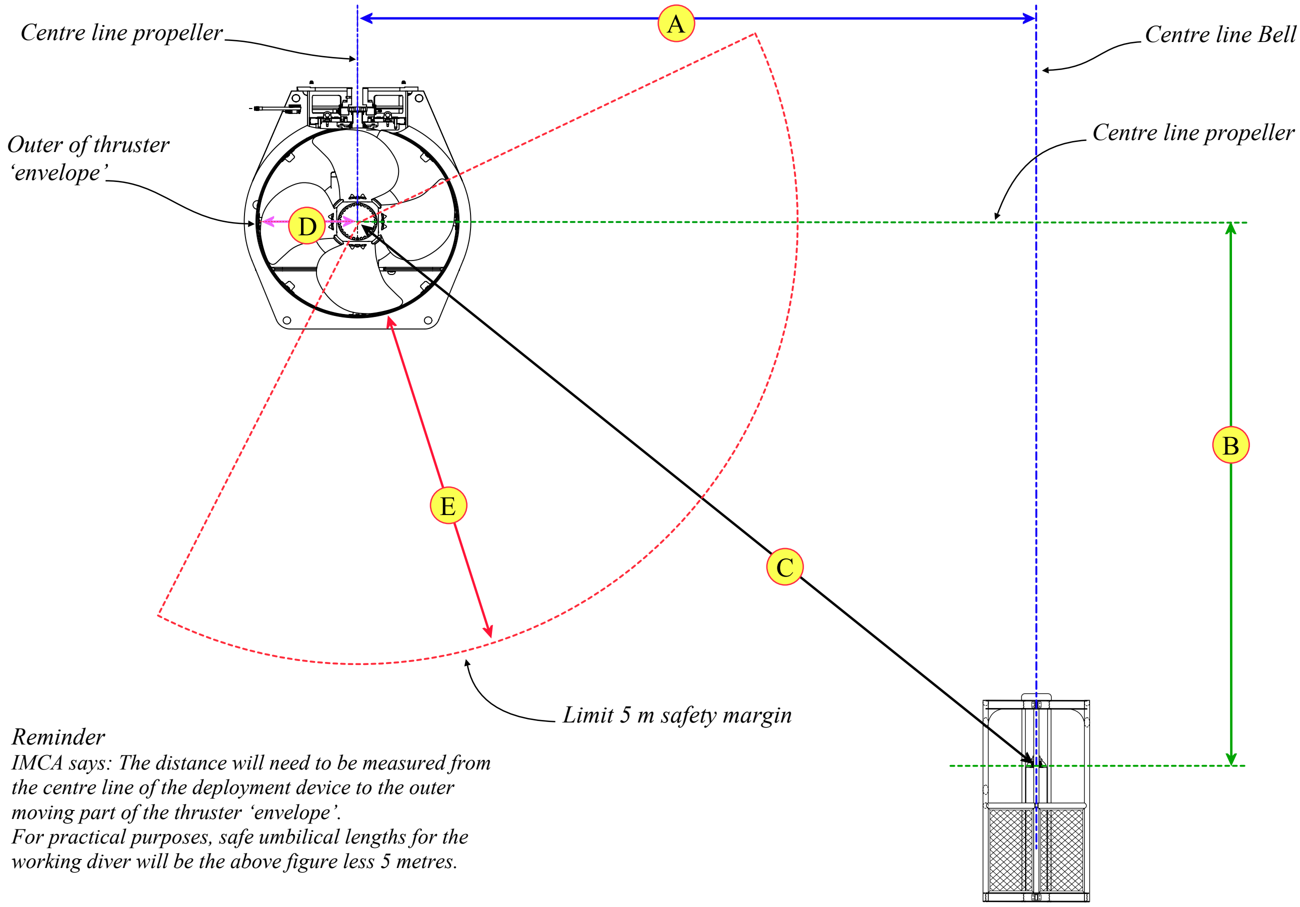


- Rules should be established for the management of the umbilicals:

- The working divers' umbilicals must be marked every 5 m. They must be tended and adjusted at all times during the operations. Also, they must be secured such that the maximum deployment range identified in the risk assessment cannot be exceeded. The devices that ensure the umbilicals must be designed such that they do not slide on the hoses, and do not damage them. Also, it must be possible to remove and reinstall them when required quickly.
- IMCA says that the length of umbilical deployed should be kept to a minimum to prevent it from becoming snagged and to permit easier recovery of a diver in an emergency, particularly when currents are present. At the same time, allowance should be made for vessel movement within the DP footprint. Also, the bellman should monitor the marking and relative position of the umbilical, and immediately inform the supervisor of any concern regarding its safety.
- Also, using negatively buoyant umbilicals may be a safer solution when diving close to propellers.
- All organizations say that the tending point is defined as the in-water point from which the diver's excursion umbilical can be securely tended. Tending can be achieved safely by employing:
  - The tender/bellman located in the deployment device from which the working diver is deployed
  - A additional in-water tender located in an additional device deployed from the DSV, such as a stage or gondola.
  - An unmanned in-water tending point, also deployed from the DSV.

4.4.1.3 - Calculate the divers' umbilicals lengths

The Pythagorean theorem is normally used to calculate the distance of the umbilical according to the recommendations indicated in section 4.4.1.2.
This theorem, which is also called the "Pythagorean equation", says that the square of the hypotenuse is equal to the addition of the squares of the two other sides. So, to obtain the hypotenuse "C" of the lengths "A" & "B" in the drawing below, we can use the formula "$A^2 + B^2 = C^2$", and then extract the square root of "C^2" to obtain the real value of "C".



The calculation of the umbilical length of the working diver consists of finding the hypotenuse *(Distance C)* of the distances A & B, from which the radius of the thruster *(Distance D)* and the safety margin (5 m) from the "outer moving part of the thruster envelope" *(Distance E)* are removed:

- The distance "A" is the distance from the center of the thruster to the center of the deployment device
- The distance "B" is the center of the thruster to the point of deployment of the umbilical
- The distance between the centre of the thruster and the waterline (surface of the sea along the hull) must be measured. Note that for a precise calculation of the hypotenuse, the computation must be performed using the vertical distance from the centre of the thruster to the point of deployment at depth (distance B). However, the gap between the centre of the thruster and the waterline must be taken into account to obtain rounded depths starting from the waterline because the recommended reference to adjust the bell is its depth from the surface of the sea. For example, if the centre of the propeller is at 4.5 m below the waterline, the 10 m depth from the waterline is 5,5 m below the centre of the thruster, and the 20 m depth is at 15.5 m from the centre of the propeller, etc. Besides, the distance of the reference point on deck, which is the point from which the length of umbilical deployed is measured, should also be evaluated.
- When the distances are evaluated, apply the formula $A^2 + B^2 = C^2$
- Extract the square root of C^2 to obtain the distance C
- When the distance "C" is obtained, remove the distance "D" *(Radius Thruster)* and "E" *(5 m safety margin)* to obtain the maximum distance of umbilical that can be deployed.
- As the vertical distance "B" of the umbilical is calculated from the centre of the propeller, the distance from this point to the waterline must be added to obtain the depths to be indicated on the drawing. Using the previous example, 5.5 m from the centre of the propeller is 10 m from the waterline (surface of the sea), so the distance to indicate on the reference drawing. Also indicate the distances of the reference point on deck.

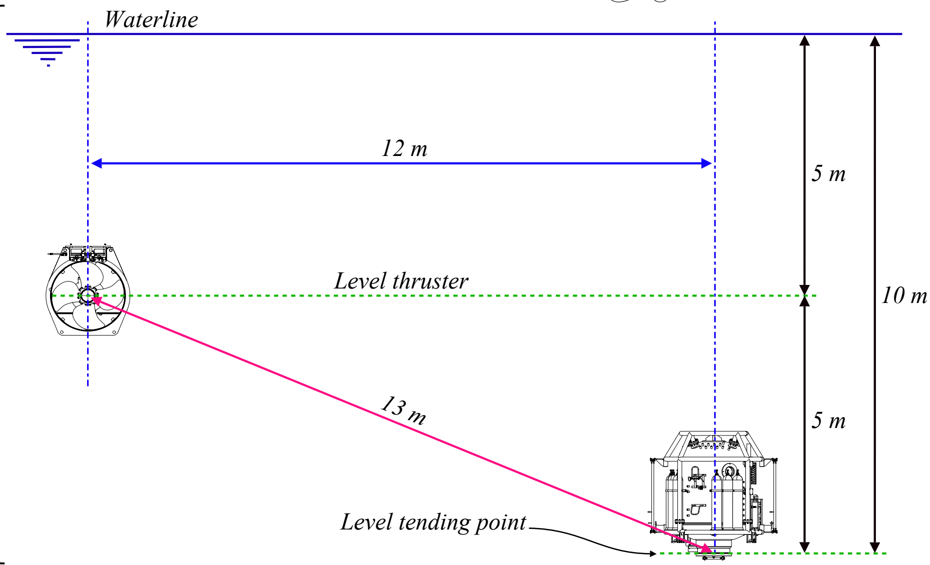
The same method can be used for the calculation of the maximum allowable distance of the rescue diver except that the safety margin is 3 metres instead of 5 m, or by adding 2 metres to the working diver umbilical lengths.

Note that this model does not take into account the fact that the vessel can be ballasted or de-ballasted during the diving operations, which will change the draft of the ship, and so the parameters used for the umbilical length calculation. Because the vertical reference used is the depth of the bell, the hypotenuse can vary as the actual depth of the bell can be above or below the level initially taken for reference. That can be visualized using the following example:

Initial status:

- *The gap between the centre of the thruster and the waterline is 5 metres.*
- *The horizontal of the bell distance from the centre of the thruster is 12 m,*
- *When the bell is lowered at 10 metres, the gap between the centre of the thruster and the tending point in the bell is 5 metres.*

As a result, the length of the hypotenuse is 13 metres.

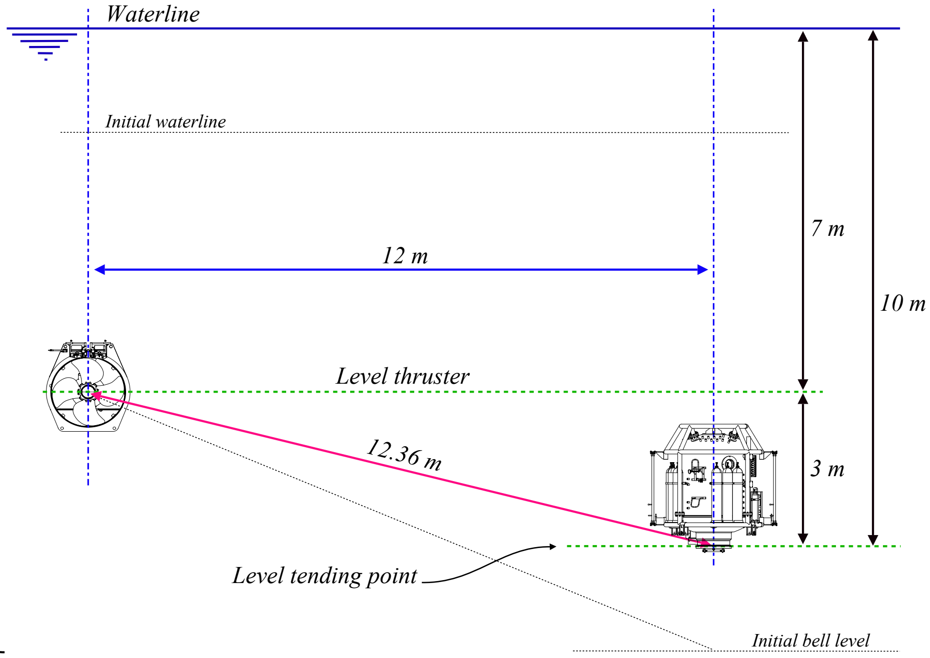


If the vessel is ballasted 2 m deeper the initial status:

- *The draft of the ship is increased of 2 m.*
- *The waterline is 2 m closer to the deck.*
- *The thruster is 2 m deeper.*

Thus, the gap between the centre of the thruster and the waterline is 7 metres, and when the bell is lowered at 10 metres below the waterline, the distance between the centre of the thruster and the tending point in the bell is 3 metres.

As a result, the length of the hypotenuse is 12.36 metres instead of 13 metres. So, the initial distance is longer.

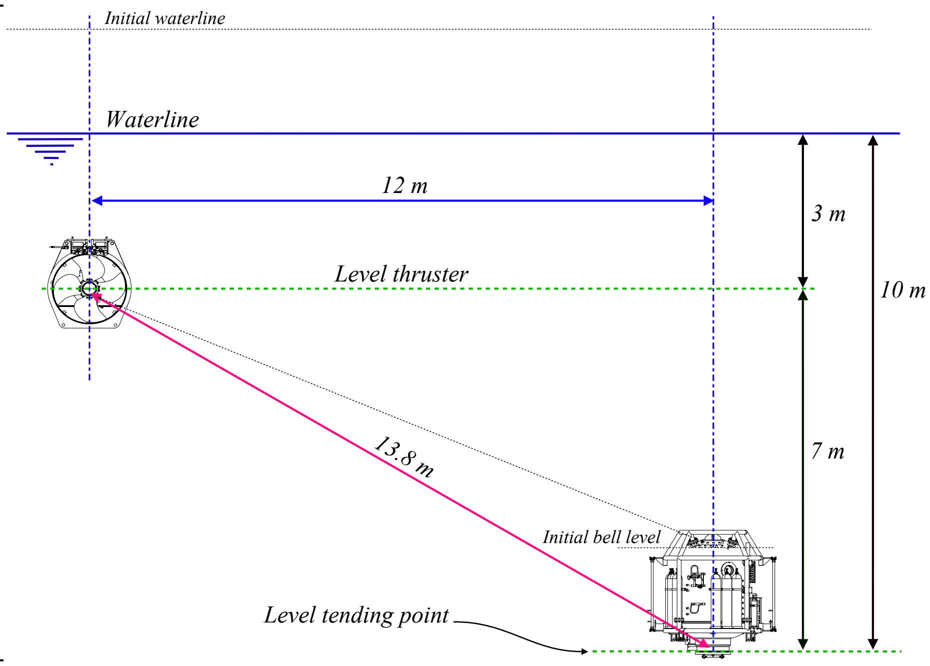


If the vessel de-ballasted 2 metres above the initial status:

- *The draft of the ship is 2 m shallower.*
- *The distance from the waterline to the deck is increased of 2 m.*
- *The thruster is 2 m shallower.*

Thus, the gap between the centre of the thruster and the waterline is 3 metres, and when the bell is lowered at 10 metres below the waterline, the distance between the centre of the thruster and the tending point in the bell is 7 metres.

As a result, the length of the hypotenuse is 13.8 metres instead of 13 metres. So, the initial distance is shorter.



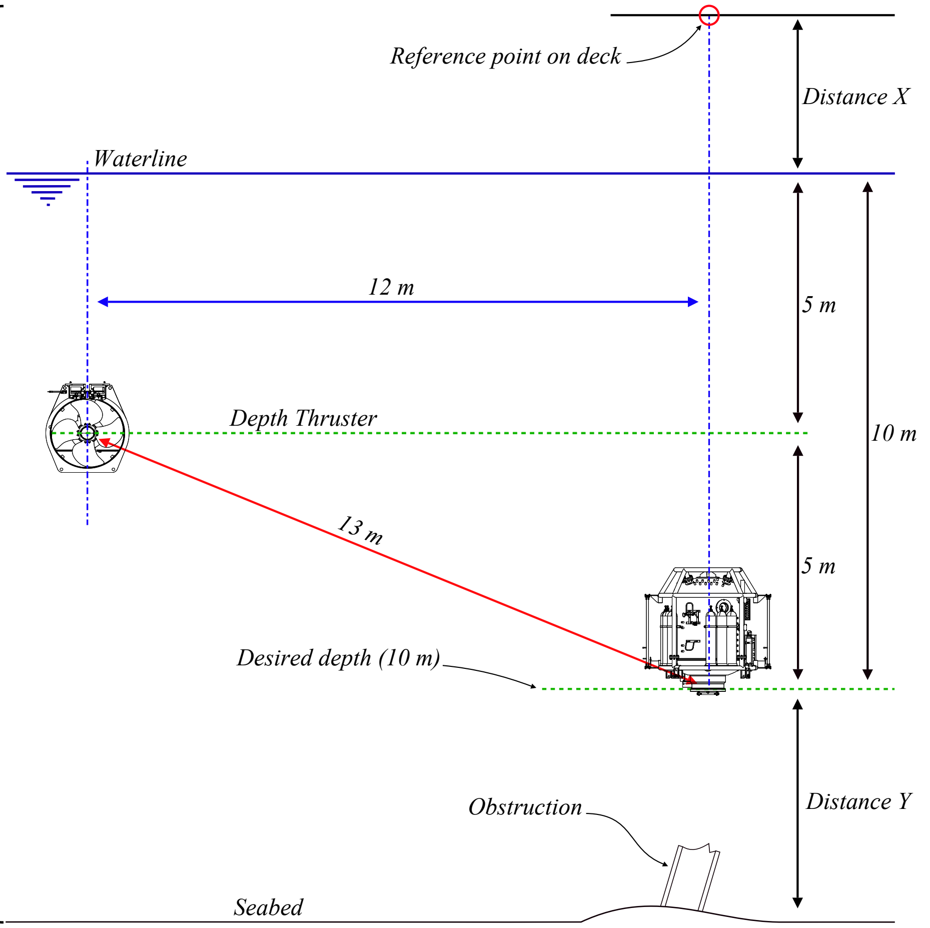
As a conclusion of the above, calculate specific deployment depths for each situation is too complicated and would be confusing for the team. So, the solution is to publish a document that can be used safely, whatever the draft of the vessel. For this reason, when a ship is subject to ballasting and de ballasting, the waterline to select for the calculation of the incremental depths should be the one when the boat is at its maximum draft.

Note that it is usual to check the depth of deployment of the bell using the length of cable deployed from a reference point on deck. However, in the case of a vessel ballasting and de-ballasting, this reference must be adjusted according to the draft of the boat to deploy the bell at the desired depth. If this modification is not implemented, the draft of the vessel varies, and the depth at which the bell is deployed varies accordingly because the length of cable deployed remains the same. As an example, if the vessel is ballasted to have two more metres draft, the reference point on deck is also lowered 2 m, so the bell is 2 metres deeper than calculated initially if it is not readjusted *(see in the scheme below)*. The bell can also be two metres above the planned depth if the boat is de-ballasted 2 m. As a result, the reference on deck is not a valid reference for the depth of deployment of the bell at the desired depth if it remains unchanged.

Initial status:

- *The gap between the centre of the thruster and the waterline is 5 metres.*
- *The horizontal distance of the bell from the centre of the thruster is 12 m.*
- *When the bell is lowered at 10 metres, the gap between the centre of the thruster and the tending point in the bell is 5 metres.*
- *The length of the hypotenuse is 13 metres.*
- *The distance between the thruster and the reference point on deck is always the same. On the drawing , this reference point is 3 m above the waterline (distance X).*

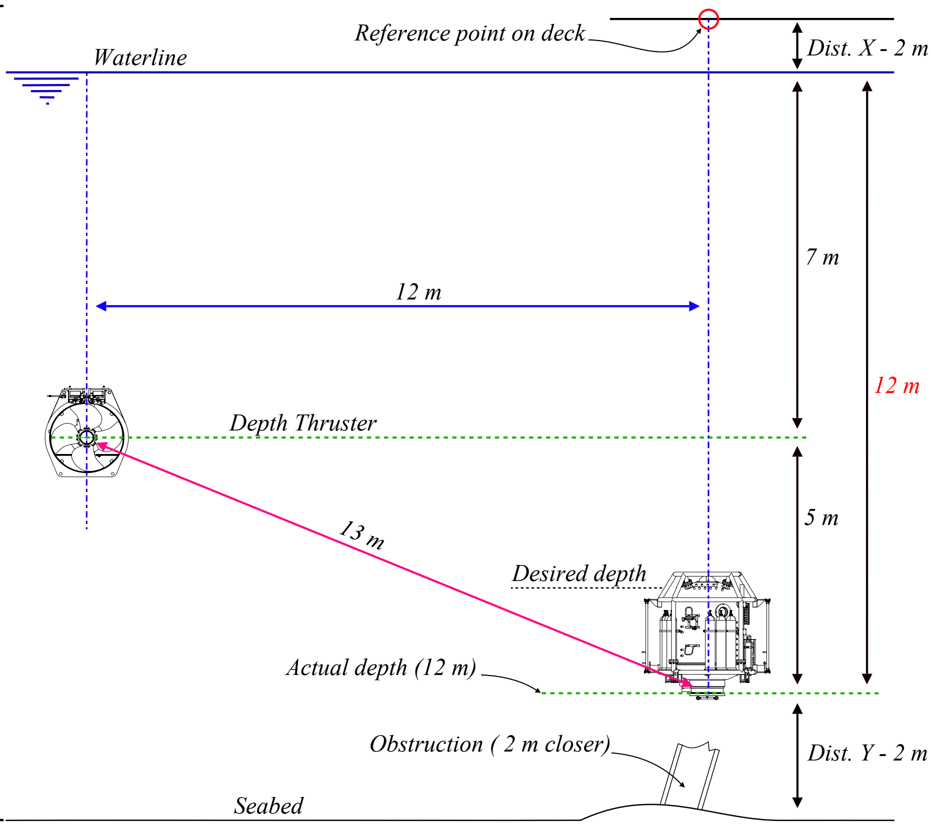
As a result, the bell is deployed at 10 m and its gap from the seabed is the distance Y.



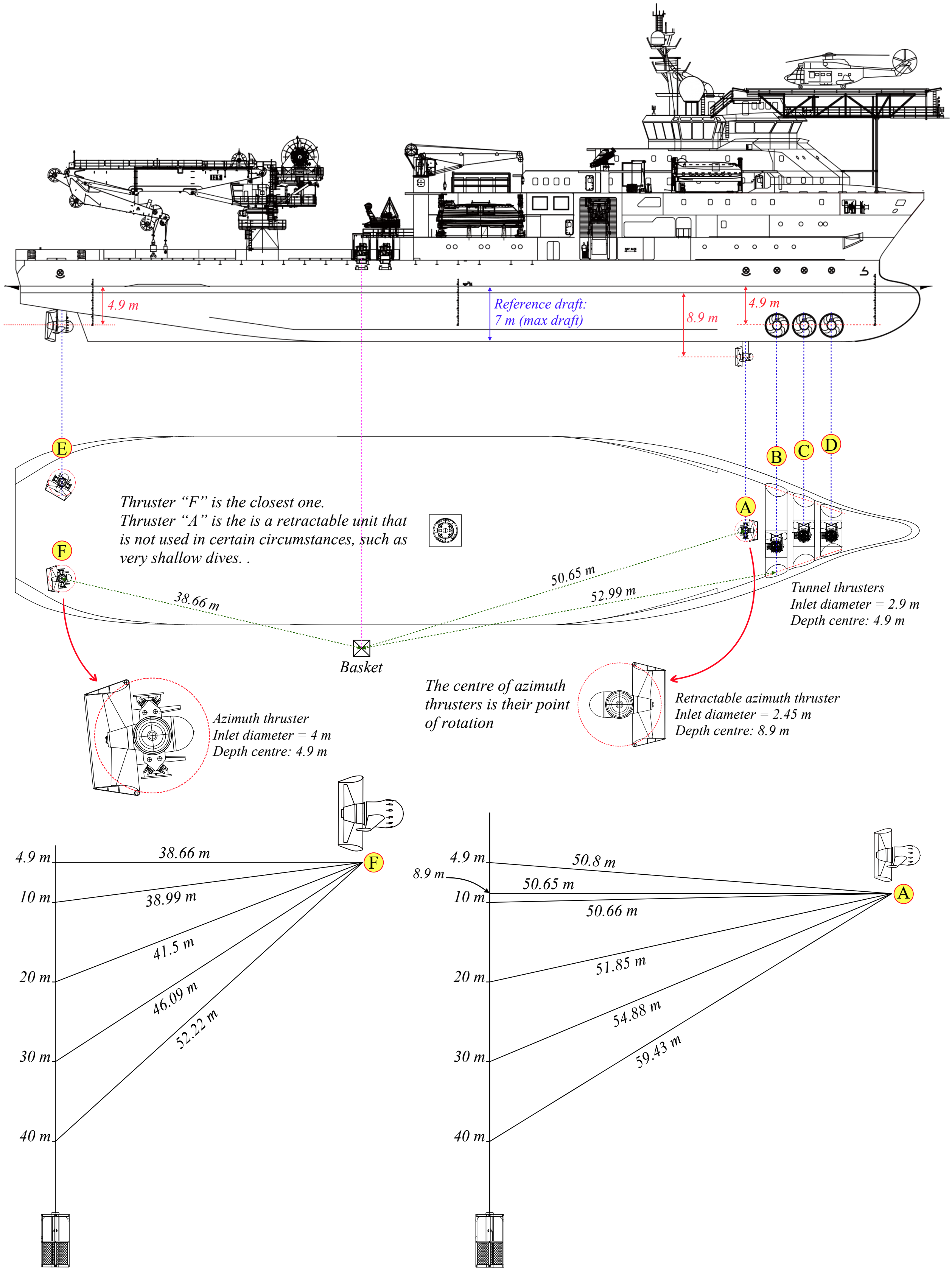
If the draft of the vessel is increased of 2 m:

- *The gap between the centre of the thruster and the waterline is now 7 metres.*
- *The horizontal distance of the bell from the centre of the thruster is unchanged,*
- *The gap between the centre of the thruster and tending point in the bell is still 5 metres.*
- *The length of the hypotenuse is still 13 metres.*
- *The distance between the thruster and the reference point on deck is always the same.*
- *The reference point is now 1 m above the waterline (distance X - 2 m).*
- *As the length of cable deployed is not modified, the bell is now at 12 m instead of 10 m.*

As a result, the gap from the seabed is the distance Y minus 2 m and the bell is closer to hazards.



Another problem that must be taken into account is to verify the exact position of the thrusters to evaluate which one is the closest to the bell/basket.
The lateral view of the vessel is insufficient for this calculation as the thrusters have to be located horizontally and vertically. For this reason, a plan view of the bottom of the ship is to be used to see their exact horizontal position. In complement, the depth of each propeller must be evaluated, so we can have an idea of their position in three dimensions.
As an example, we can see in the plan view below that the thrusters F, A, & B are not aligned with the basket, so their exact distance is to be calculated using the "Pythagorean equation". Note that the point from which the horizontal distance of the azimuth thrusters to the centre of the basket is to be calculated is their point of rotation.
When the thrusters are located horizontally, the depth of the centre of their propeller is to be used to locate them on the vertical axis.
Note that, as indicated previously, the hypotenuses are calculated from the centre point of each device, and the safety limits are added later.



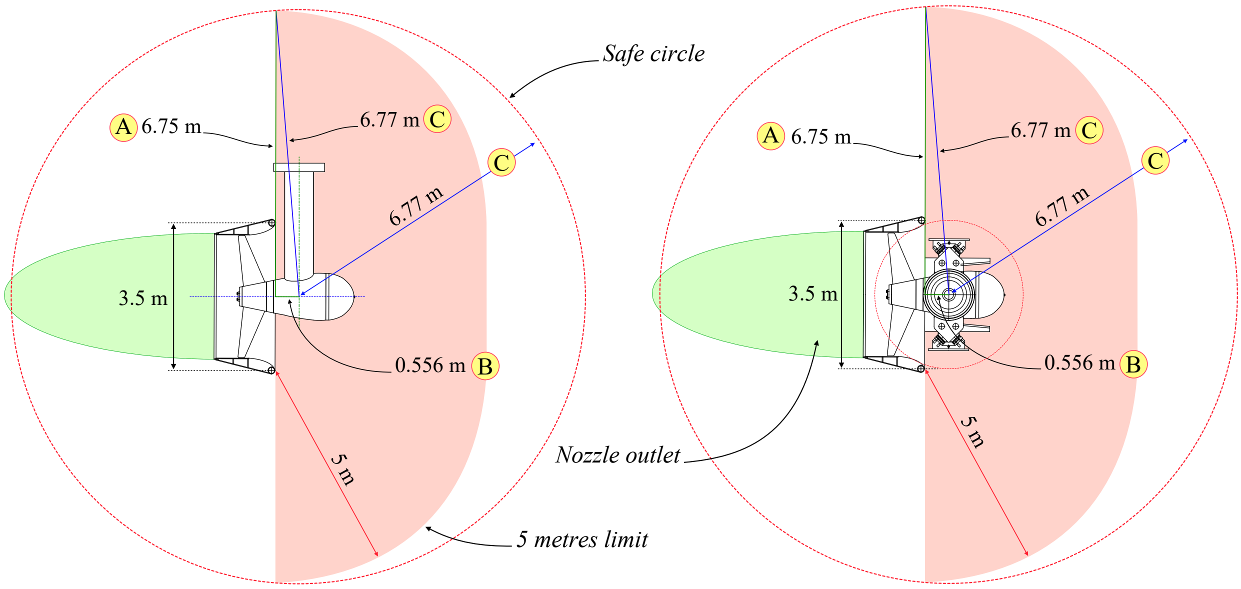
When the thrusters are located, the hypotenuses of the closest thruster are to be calculated for every 10 metres from the first level of deployment and up to the depth where the propellers are too far to represent a danger. This depth also depends on the length of umbilical available in the bell. Usually, the calculation is halted between 60 and 80 metres.

Note that if the closest thruster is retractable, as in the example on the previous page, the nearest unit when this retractable thruster is not used becomes the reference. Also, even though the diver umbilical must be restricted to the closest thruster, it is wise to calculate the distances for the other thrusters as strong currents or sudden vessel moves may push the bell toward them. This problem is more detailed in point 8.4.1.4.

When the lengths axis to axis are calculated, the safety precautions indicated by IMCA and ADCI *(external envelope of the moving parts and 5 m limit),* and mentioned previously must be implemented.
Regarding this point, note that azimuth thrusters rotate 360º around their axis and that their propellers are installed eccentric so that the procedure to evaluate the safe distance from these propellers is different from the one used with tunnel thrusters and fixed propellers. For this reason, the drawings from the manufacturer should be used to evaluate the safe limit into which the thruster can rotate and always be inside a 5 m safety margin as a minimum.
Note that depending on the model of the thruster, the propeller can be installed on the back of the pivoting point, or on the front of it, which influences the procedure of calculation.

- 1 - Procedure for a thruster with the propeller installed on the back of the pivoting point:

- The first step consists of drawing the limit of the propeller "envelope", and the 5 metres safety limit from this "envelope". Note that if the diver is forward the inlet of the propeller, he will be drawn to it. For this reason, the 5 m limit from the inlet of the propeller is outlined in red in the drawing below. However, if the diver is behind the propeller, so roughly in the area figured in green, he will be violently ejected. The spaces between these two zones are sectors that are also to be considered unsafe.
  Note that the 5 m limit from the envelope of the propeller is similar on a vertical and horizontal axis. So we can imagine that the 5 m limit is a flatted half-sphere in which the center point is the crossing of the axis of the propeller with the horizontal rotation axis.
- When the propeller envelope and the 5 m limit are evaluated the circle into which the thruster can rotate without being at less than 5 m from this limit must be evaluated. For thrusters with the propeller on the back of the pivoting point, the proposed procedure is the following:
  - Calculate the distance "A" from the axis of the propeller to the external of the 5 m limit: In the example below, 5 m limit + radius propeller "envelope" (1.75 m) = 6.75 m . .
  - Calculate the distance "B" from the edge of the propeller "envelope" to the pivoting point of the thruster. In the example below, it is 0.556 m.
  - Calculate the hypotenuse "C" of "A" and "B".
  - The Hypotenuse "C" obtained is the radius of the safe circle into which the thruster can rotate.

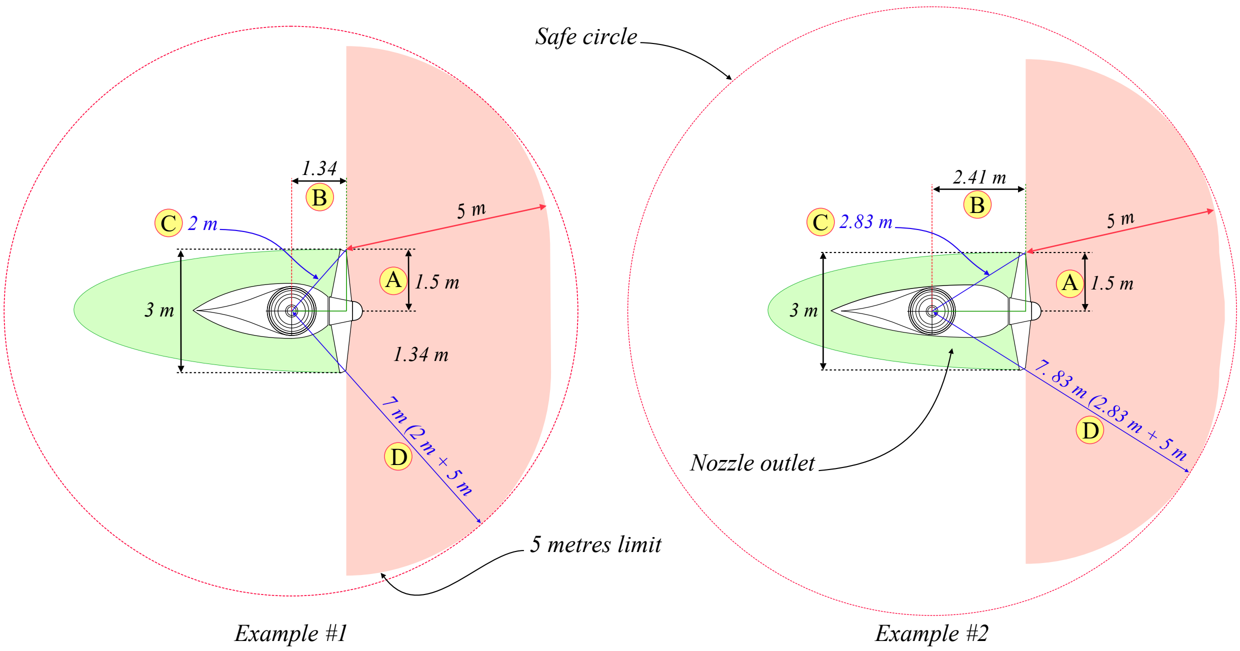


Side view thruster: Vertical axis *Plan view thruster: Horizontal axis*

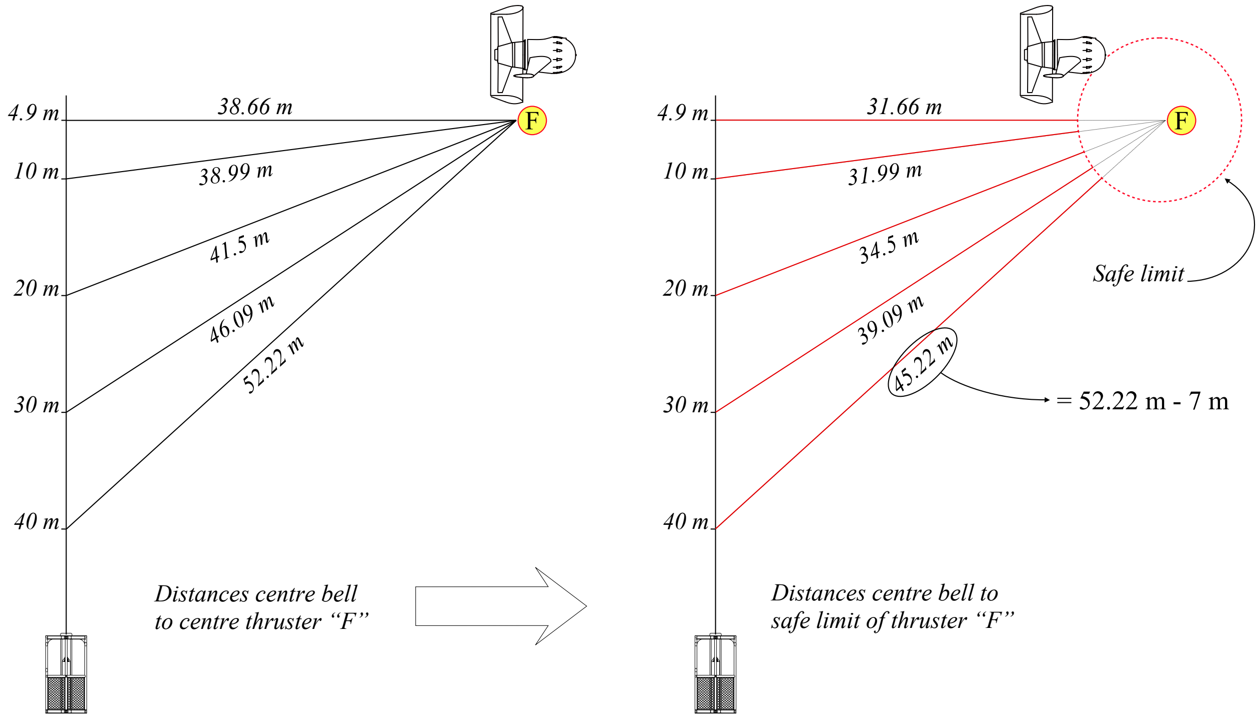
- 2 - Procedure for a thruster with the propeller installed on the front of the pivoting point:

- The first step is similar to the one implemented with thrusters with the propeller installed on the back of the pivoting point. Note that for convenience in the example below, the edge of the blade is taken as reference of the external limit of the envelope of the moving parts.
- When the propeller envelope and the 5 m limit are evaluated the circle into which the thruster can rotate without being at less than 5 m from this limit must be calculated. The proposed procedure is the following:
  - Calculate the distance "A" from the axis of the propeller to the external limit of the envelope of the moving parts: In the example #1 & #2 below, this distance is 1.5 m.
  - Calculate the distance "B" from the edge of the propeller "envelope" to the pivoting point of the thruster. In the example #1 below, it is 1.34 m, and in the example #2, it is 2.41 m.
  - Calculate the hypotenuse "C" of "A" and "B".

- The length of Hypotenuse "C" obtained is added to the 5 m limit: That gives a distance of 7 m in the example #1, and a distance of 7.83 m in the example #2.
- The distance "D" obtained is the radius of the safe circle into which the thruster can rotate.



When the sphere into which the thruster can rotate within the 5 m safety limit is established, its radius must be removed from the hypotenuse of the axis of the bell to the central point of the thruster, as performed with tunnel thrusters or fixed propellers. As an example, if the radius of the safe circle is 7 m, this distance is merely removed from the hypotenuse as in the drawing below:



When the maximum umbilical lengths are calculated, it often happens that the distances found are precise at the centimetre, and sometimes the millimetre. For practical reasons, these values should be rounded to the immediate shorter decimetre. Example: 49.766 m should be turned to 49.7 m.

The installation of the safety fastenings of the umbilicals should be prepared before launching the dive. The restrictions for the rescue diver are those indicated previously for fixed propellers and tunnel thrusters. Thus 2 m is to be added to the limits established for the working divers. These distances should be shown in the scheme and the table where the maximum umbilical lengths are displayed.

Also, when wet bells are used, it is usual that the bellman acts as the rescue diver. In this case, the classical procedure above is to be implemented as well.

Note that the calculations indicated above should be provided by the manufacturers of Diving Support Vessels. It is, unfortunately, not always the case. The problem is more complicated with boats of opportunity because they are multipurpose ships that are not specifically designed for diving. In case that these evaluations are missing, they must be performed when selecting the vessel as the distance between propellers and the bell is a criterion of selection.

4.4.1.4 - Deployment of divers using in-water tending points

As indicated in section 4.4.1.2, the length of umbilical deployed should be kept to a minimum. So when it is possible to do it, it is preferable to move the vessel above a target instead of extending the umbilicals to their maximum ranges. Also, at depths below 60 m, the distance from the bell the diver can go does not depend on the proximity of the thrusters, but on the length of umbilical available in the bell and on the capacity of his bailout to allow for a safe return to the bell. However, shallow dives near facilities can be disturbed by problems of access of the boat to some areas due to elements such as platform overhangs, flare towers, lifeboats launching area, bridges, and others.
For this reason, it may be necessary to deploy the divers beyond the calculated safe umbilical length. As indicated in section 4.4.1.2, that can be performed using a 2nd tending point, which can be a basket or a piece of similar equipment such as a squared frame, suspended from a crane, or a similar deployment device located on the vessel. The diver usually passes through this structure to encage his umbilical so that it is secure and can continue sliding. Then, the diver can move forward from this point to the job site *(see the drawing in point 4.4.1.2)* without the risk to be drawn to the closest propeller, despite the extra umbilical length deployed.
The device used to deploy the 2nd tending point must be able to hold a static position when deployed. “A-frame” shaped deployment devices are considered very safe for this reason, and are also simple to implement.

IMCA D 010 provides useful guidelines regarding the methods to be implemented for the safe operation of a 2nd tending point. As indicated in point 8.4.1.2, this guideline classifies the additional tending points into “active” and “passive” tending points, and thus says the following rules:

- 1- Active in-water tending point (manned):

  An active tending point is the arrangement described above with a diver acting in it as intermediate in-water tender. the following criteria should be met:

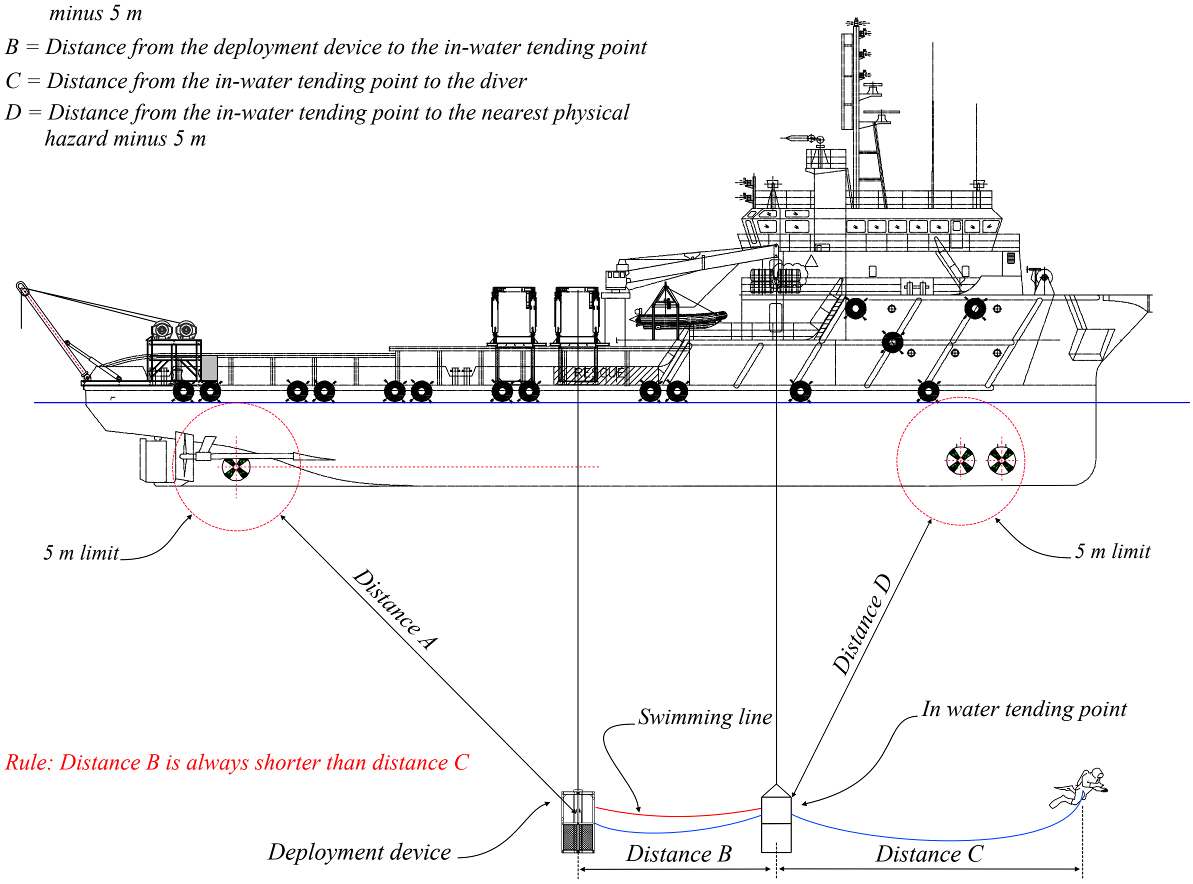
  - The tending point is held in a static position relative to the vessel that should be confirmed by a beacon.
  - The length of the umbilicals must be restrained as indicated in the previous points.
  - A swim line is fixed between the deployment device and the manned in-water tending point.
  - The working diver’s umbilical is secured to the swim line between the deployment device and the manned in-water tending point at the maximum allowable excursion distance from the in-water tending point.
  - The in-water tender’s umbilical and that of any standby diver is secured to the swim line between the deployment device and the manned in-water tending point at the calculated maximum excursion distance for the working diver from the in-water tend point plus two metres.
  - In the event of the tender becoming incapacitated, the working diver should have sufficient length of umbilical to return to the deployment device without disconnecting his umbilical from the swim line. For this reason, his maximum allowable excursion beyond the in-water tending point is always greater than the distance from the deployment device to the in-water tending point *(see below)*.

A = Distance from the deployment device to the nearest physical hazard minus 5 m

B = Distance from the deployment device to the in-water tending point

C = Distance from the in-water tending point to the diver

D = Distance from the in-water tending point to the nearest physical hazard minus 5 m



- Procedures should be in place to allow for the recovery of a diver in an emergency.
- A risk assessment should be carried out, and the additional measures identified should be implemented.

- 2- Passive in-water tending point (unmanned):

A passive tending point is the arrangement described above but without a diver acting in it as intermediate in-water tender. The procedures that should be applied are the same as those of active tending point except the following:

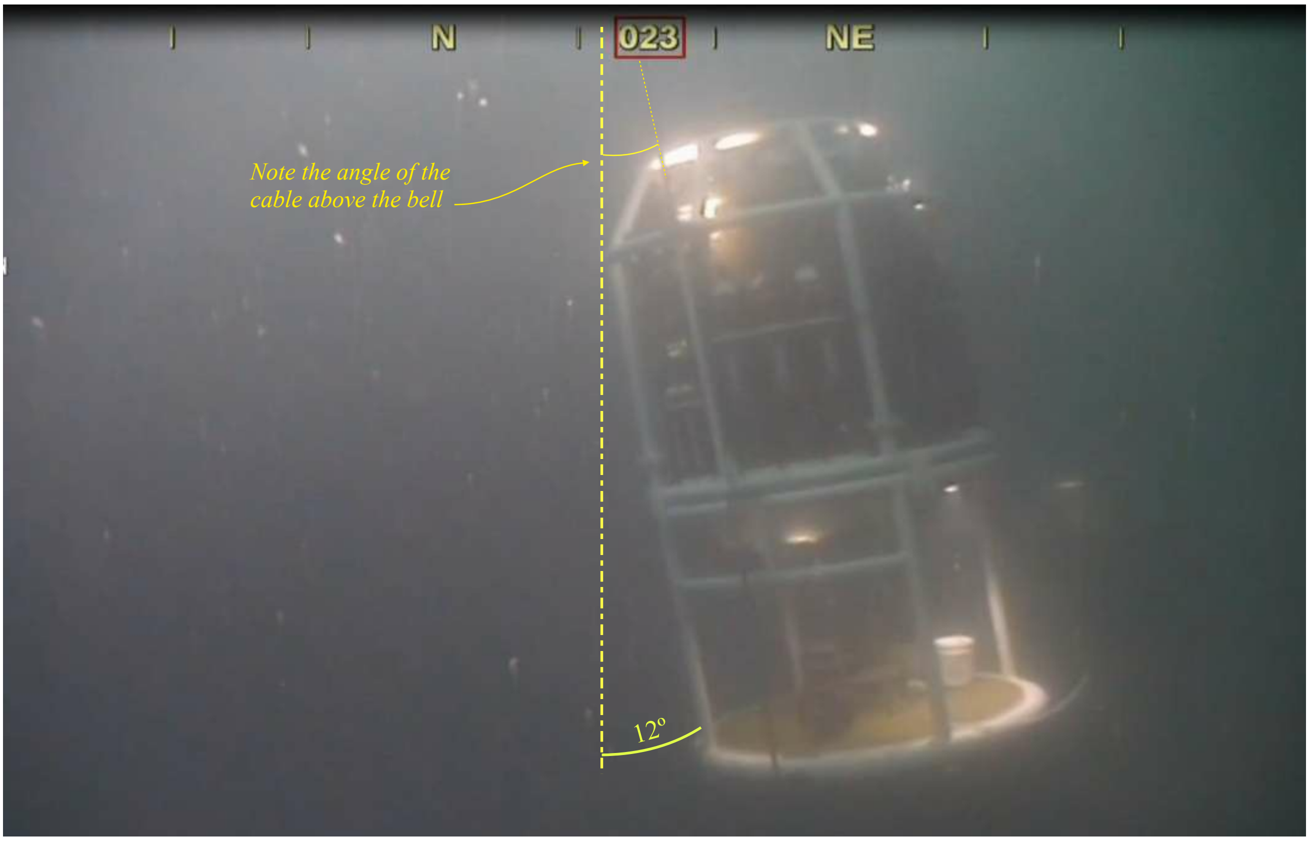
- The bellman's umbilical and that of any standby diver is secured to the swim line between the deployment device and the unmanned in-water tending point at the calculated maximum excursion distance for the diver from the in-water tending point plus two metres.
- If a problem begins to arise when two divers are on passive tending, then one diver should return to the tend point and revert to active tending.

4.4.1.5 - Influence of the underwater currents and sudden moves of the ship on the bell/basket and the umbilicals

Underwater currents that can push the bell/baskets and the umbilicals may establish during the diving operations. Also, due to the density of the water, the bell/basket cannot follow an unexpected move of the boat vertically and thus is hung with an angle during these periods.

The action of the current on the umbilicals can result in large buckles, and an excessive length deployed. This problem is solved with some last generation bell umbilicals that are provided with a dynamic tensioning system that permanently recovers the excess of slack, and maintains it in tension. However most wet bell are not equipped with such systems that are more common with saturation diving bells, and their umbilicals are often partly deployed manually. For this reason, the umbilical of such systems should be secured to the bell wire at regular intervals along its length to prevent it from being attracted by the thrusters. The same procedure should be implemented for the divers umbilicals deployed with a basket. The whips that are used to secure the umbilical should be designed such that they do not damage it and must be able to slide easily along the cable. Also, the distances where these whips are installed on the umbilical must be recorded. Usually, endless soft slings or rope slings with large carabineers that are installed on the main cable of the bell/basket are used for this purpose. The lateral wires can also be used in case of several divers are deployed or the wet bell is used like a basket.
IMCA says that when securing the umbilical along the cable is not an appropriate solution, a risk assessment should identify the maximum safe length of umbilical, which can be deployed in relation to the depth of the bell/basket.

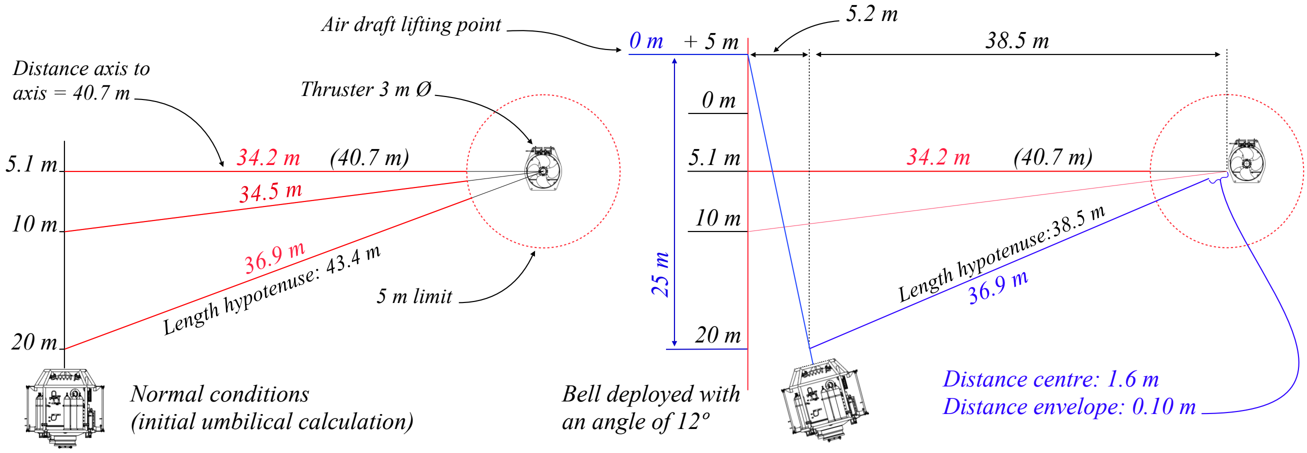
Another problem linked to strong currents is that they can push the bell/basket, which is lowered with an angle as in the photo of the closed bell below instead of vertically. As a result, the bell is not at the planned location, and the initial calculation for the deployment of the divers' umbilicals can be significantly altered. A similar effect may happen in the case of an unexpected violent move of the vessel.



Note that in such cases, the deployment cable usually forms a catenary. However, this catenary varies with the pressure resulting from the current, the depth of the bell, or the force of the sudden pull of the vessel. So, it is challenging to predict its exact curve, and for this reason, only the angle is considered.
Considering the photo above taken at a depth of 50 m, so 60 m below the lifting point, and the visible angle of the bell of 12 degrees, we can evaluate its horizontal distance from the "vertical" of the moon pool to approximately 12.6 m.

The photo of this example has been taken when the bell was descending to a deeper depth where there was no current. So the only problem was to make corrections to be close to the worksite. However, a bell that is not deployed vertically may become a serious problem during shallow dives, due to the proximity of the propellers.
To illustrate it, we can take the example of a bell with a lifting point at 5 m above the waterline, the centre point of the nearest tunnel thruster of 3 m diameter at 5.1 m below the waterline, and a horizontal distance of 40,7 m from the centre of the bell. So, the 5 m safety limit at 6,50 m from the centre of this thruster.

- Under “normal” conditions (initial calculation), the length of umbilical available at 20 m is 36.9 m, and the vertical distance from the pulley of the A-frame is 5 m (air draft)+ 20 m (water depth)= 25 m.
- If the bell is lowered with an angle of 12º from a vertical distance of 25 m, it is shifted 5,2 m from the vertical point. Thus the hypotenuse from this new position to the center of the thruster is 38.5 m.
- If the diver keeps the initial umbilical length of 36.9 m, the end of his umbilical is at 1.6 m from the centre of the thruster and 10 cm from the “envelope”. Thus, we can say that this thruster can catch the diver.

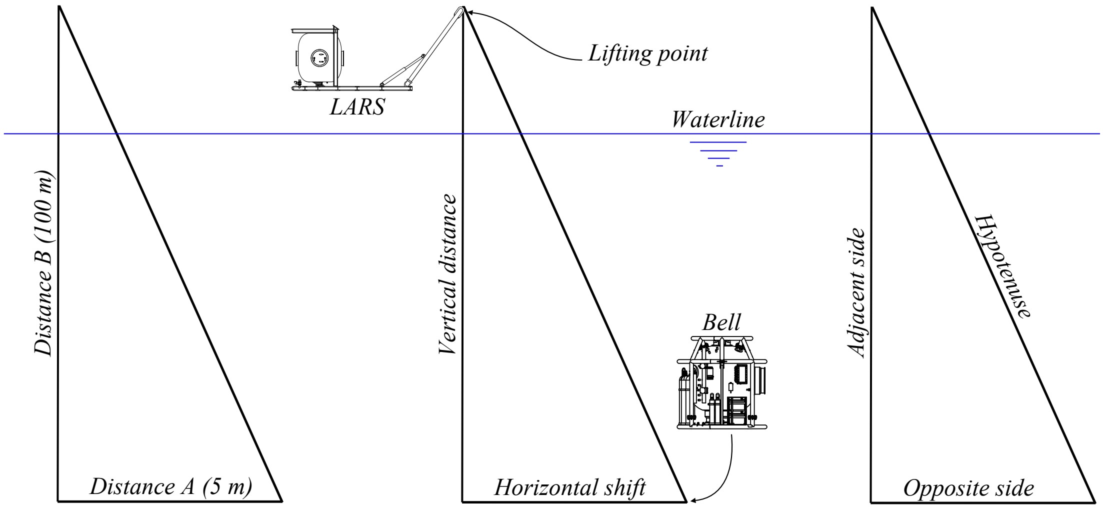


The table below shows the horizontal the deviations resulting from the angles at various distances from the lifting point.

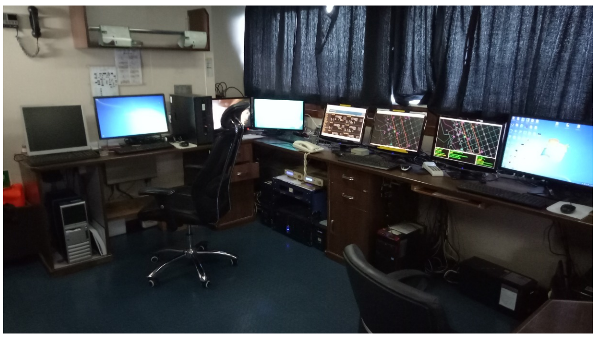
		Angle							
		2°	**4º**	**6°**	**8º**	**10º**	**12º**	**14º**	**16º**
Vertical distance	**5 m**	0.2 m	0. 3 m	0.5 m	0.7 m	0.9 m	1 m	1.2 m	1.4 m
	10 m	0.3 m	0.7 m	1 m	1.4 m	1.7 m	2.1 m	2.4 m	2.8 m
	15 m	0.5 m	1 m	1.6 m	2.1 m	2.6 m	3.1 m	3.7 m	4.2 m
	20 m	0.7 m	1.4 m	2.1 m	2.8 m	3.5 m	4.2 m	4.9 m	5.6 m
	25 m	0.9 m	1.7 m	2.6 m	3.5 m	4.4 m	5.2 m	6.1 m	7 m
	30 m	1 m	2.1 m	3.1 m	4.2 m	5.2 m	6.3 m	7.3 m	8.4 m
	35 m	1.2 m	2.4 m	3.7 m	4.9 m	6.2 m	7.3 m	8.5 m	9.8 m
	40 m	1.4 m	2.8 m	4.2 m	5.6 m	7.2 m	8.4 m	9.8 m	11.2 m
	45 m	1.6 m	3.1 m	4.7 m	6.3 m	8.2 m	9.4 m	11 m	12.6 m
	50 m	1.7 m	3.5 m	5.2 m	7 m	9.2 m	10.5 m	12.2 m	14 m
	55 m	1.9 m	3.8 m	5.8 m	7.7 m	10.2 m	11.5 m	13.4 m	15.4 m
	60 m	2.1 m	4.2 m	6.3 m	8.4 m	11.2 m	12.6 m	14.7 m	16.7 m
	65 m	2.3 m	4.5 m	6.8 m	9.1 m	12.2 m	13.6 m	15.9 m	18.1 m
	70 m	2.4 m	4.9 m	7.3 m	9.8 m	12.2 m	14.7 m	17.1 m	19.5 m
	75 m	2.6 m	5.2 m	7.9 m	10.5 m	13.1 m	15.7 m	18.3 m	20.9 m
	80 m	2.8 m	5.6 m	8.4 m	11.2 m	14 m	16.7 m	19.5 m	22.3 m
	85 m	3 m	5.9 m	8.9 m	11.9 m	14.8 m	17.8 m	20.8 m	23.7 m
	90 m	3.1 m	6.3 m	9.4 m	12.6 m	15.7 m	18.8 m	22 m	25.1 m
	95 m	3.3 m	6.6 m	9.9 m	13.3 m	16.6 m	19.9 m	23.2 m	26.5 m
	100 m	3.5 m	7 m	10.5 m	14 m	17.4 m	20.9 m	24.4 m	27.9 m

There are several methods that can be used to calculate the horizontal shift from the vertical of the launching point:

- The table displayed on the previous page gives approximate horizontal shifts resulting from angles from 2º to 16º, calculated from the vertical alignment of the launching system on deck. Calculating the height of this launching point on deck is very important: It can be found by adding the height of the final pulley of the Launch And Recovery System (LARS), to the air draft of the deck where it is installed.
  This table gives measurements up to 100 m from the point of deployment above the deck. Deeper depths can be evaluated by adding the differential values to the 100 m limit of the table: As an example, for 120 m, add the value for 20 m to the one for 100 m.
- Trigonometry can be used for more precise evaluations. The procedures proposed are similar to those used by carpenters to calculate the slope of a roof. Note that a slope can be displayed in % and in degrees.
  - The procedure proposed to calculate the slope of the deployment device in % consists to divide the horizontal shift by the vertical length, and to convert it in percentage. So, using the drawing below, (distance A / distance B) x 100. As an example, if a bell is 100 m below the last pulley of the LARS, and is shifted 5 m from the theoretical vertical point, the percentage of the "slope" is 5% , which values are 100 (5/100). If the shift is only 4 m, the percentage of the "slope" is (4/100) x 100= 4% .



  - To calculate the slope in degrees, 1st calculate the tangent: Tangent = opposite side / adjacent side, which is in fact the distance of the shift divided by the vertical distance. Thus for a bell that is 100 m below the last pulley of the LARS that is shifted 5 m from the theoretical vertical point, we divide 5 metres by 100 metres to obtain 0.05, which is a value in radians (the real value is 0,0499583957).
    Then, we need to to convert the radians into degrees: To do it apply the formula 0.05 x 180 x 3.14 (Pi). The result obtained is 2.8624, which is the value in degrees with minutes in decimals.
    To covert the decimal value into a sexagesimal value, consider that 2.8624 is 2 + 0.8624. To convert 0.8624, merely multiply it by 60. Thus, 0.8624 x 60 = 51.744, which is the value of the minutes.
    Then, using the same formula, the decimal seconds are converted into sexagesimal seconds: 0.744 x 60 = 44.64. So, the value of 0.05 radians is 2° 51' 44".
  - To find the horizontal shift resulting of an angle in degrees, convert the values in degrees into radians by proceeding the opposite way of the procedure above, and then multiply the value in radian by the vertical distance B.
- The procedures above have some limitations during the diving operations as checking the angle of a cable is not an easy task without adequate tools. As a result, parallax errors may occur. Parallax errors occur when the measurement of an object's length is more or less than the true length because of the eye of the observer is being positioned at an angle instead to be adequately aligned.
  For these reasons, the use of a hydroacoustic beacon seems the best procedure to check the exact position of the bell during the dive. Note that bells are today equipped with such devices and it is also the case of divers.
  Also, surveying and mapping technicians are used to collect data to make maps of the worksite, and provide the position of divers, Remotely Operated vehicle and every item lowered to the worksite. Thus they are highly qualified to indicate the exact position of the bell and its angle of deployment if needed.



Survey station

Hydroacoustic beacons

To conclude on the procedures to be used to calculate the shift of the bell from the theoretical vertical point, it must be taken into account that the underwater current may establish suddenly, or significantly reinforce during a dive and that a failure of the positioning system is unpredictable, despite the improvements manufacturers have made. Also, obliging the diving supervisor to perform such calculations during the operations is a bad idea as he has many things to manage during the dive.

For these reasons, the maximum acceptable angle of the bell and the resulting shift from the theoretical vertical point should be entered into the calculations made for the maximum allowable umbilical lengths taking into account:

- The maximum angle of the bell during diving operations with current speeds conform to those recommended in IMCA D 067, and explained in point 5.8 of this book.
- The maximum angle that may result from a sudden loss of position of the vessel.

4.4.1.6 - To conclude with the preparation of umbilicals

The rules described by IMCA and ADCI regarding the safe distance from propellers and other hazards have probably saved numerous lives. However, these guidelines do not indicate elements such as the possibility to adjust the draft of the diving support vessel, the fact that new ships are equipped with azimuth thrusters that rotate 360 degrees, and that currents and a sudden loss of positions can impact the planned position of the bell and so corrupt the initial umbilical calculations. The main reason is that these guidelines have been emitted since dynamic positioning vessels arrived in the diving industry, and have not been changed from that time. Based on the fact that events that have not happened yesterday may happen one day, it is highly recommended to implement the procedures indicated in this chapter, even though professional organizations publish no modification of the existing rules.
Also, people calculating the umbilical lengths and those managing the dives must have common sense and wiseness.

- When performing umbilical lengths calculations, it is preferable to be a bit restrictive rather than looking to very optimum lengths. It must be considered that the 5 metres and 3 metres limits are the extreme points beyond which the divers are considered endangered. There is no law that forbids giving some more safety margins.
- As indicated, the preparation of the project is an important phase where the umbilical length calculations are to be performed accurately using the construction drawings of the Diving Support Vessel. Uncertainties regarding the design and the position of the thrusters must be solved during this period.
- Also, supervisors should be prudent and avoid using the maximum allowable umbilical lengths during the diving operations. That can be done by an appropriate study of the worksite and the possible movements of the ship, in addition to the option to use a 2nd tending point.
- The design of the vessel used for the operations is also essential: As already said in the previous point, propellers are not a big problem when the worksite is very deep, but they become a hazard during shallow operations. Thus, large boats are preferable for shallow dives. Instead, deep dives can be performed from more reduced surface supports.

Note that there are uncertainties regarding the distances at which the water ejected from azimuth thrusters can affect a diver. That is linked to the power deployed, the diameter, and the rotations per minute of the propeller. However, it seems that no specific study exists at that moment.

4.4.2 - Worksite preparation and selection of the procedures

4.4.2.1 - Main elements to take into consideration

Worksite preparation is a key ingredient for successful diving interventions. Those undertaken from Dynamic Positioning vessels involve precautions that are linked to the fact that these ships maintain their position and heading by using their propellers and thrusters through a computer-controlled machinery and position reference systems that are combined with environmental sensors and controlled from a specific station installed in the bridge of the vessel. Most of these precautions come from the professional organizations previously listed.

- The primary rule is that the vessel and the bell/basket must be positioned in such a way that escape is possible without clashing with existing structures in case of a loss of position or a full blackout of the ship. For this reason, It is recommended to ensure that the bell and its clump weight are always above or out of the way of structures or debris that may catch and damage them. Also, the divers should be ready to be recovered as soon as possible if needed, so they must be informed of all items that may become an obstacle. Note that the structures can be production platforms, mooring buoys, anchor wires, cables, and similar elements that are also hazards for the vessel. For this reason, the following investigations should be implemented before starting the first dive, and preferably during the project preparation:
    - The bottom must be investigated for debris that may harm the bell, or the taut wire if it is planned to use it. the elements found must be logged and indicated on a map.
    - Structures visible from the surface must be precisely logged and investigated underwater. Mooring lines and other items that can be obstructions for the bell must be precisely plotted and represented on the map. Note that dynamic positioning operations in an anchor pattern require particular precautions that are explained in the next point to be able to escape from it safely.
    - Pipelines, electric cables, and their associated structures such as wellheads and PLEMs (Pipe Line End Manifolds) must also be precisely logged.
    - A nav-screen displaying the worksite with the positions of the vessel, the divers and their bell, the ROV,

and any known obstruction together with the vessel's heading and environmental data, should be available to DP operators, diving supervisors, ROV supervisors, Offshore Construction Manager, clients, and every key personnel involved in the operations. The plots displayed must be updated before and during the operations.

- Direction and strength changes of the wind or the currents are likely to cause a sudden variation of the forces acting on the vessel and modify her operating conditions such that operations have to be halted to avoid a dangerous situation.
  The rule is that weather conditions are actively monitored for incoming squalls, change of the atmospheric pressure, and changes in direction and strength of the wind and the underwater currents during the operations. However, tracking the weather also implies studying the prevalent winds and currents in the area during the period planned for the activities as well as atmospheric conditions and records of storms, squalls, and other weather events that have happened during the same period of the year. This investigation has to be done during the preparation of the project.
- The selection of the reference systems that are the most appropriate is of primary importance (refer to the descriptions described in section 8.2.4). Also, precautions should be in place to avoid interferences with other reference systems or some facilities. Among the problems that can be encountered, note the following:
  - Taut wires can be caught by debris on the bottom, conflict with mooring lines, or be snagged to down-lines, or massive objects lowered by the crane. For these reasons, they should not be used in areas where potential contacts with existing structures or debris exist, and their position must be regularly checked by the onboard ROV. In addition, the operations are to be organized such that down-lines must be installed away from them, and lifting operations are not to be performed in their vicinity. Also, down-lines, swimming lines, and lifting areas must be logged on the map of the worksite where the position of the boat is also indicated.
    Another element to consider is that taut wires have some limitations regarding the depths and the weather conditions they can be used for *(see section 4.2.4.2.2)*.
  - Global Navigation Satellite Systems can lose their signal when the vessel is too close to a platform, a Floating Storage Facility, or any massive structure and may have to be replaced by another system (see section *4.2.4.2.2)*.
  - Acoustic systems are subject to interference when the vessel is close to another ship (It is mainly due to the increased thruster wash and noise), or working in very shallow waters.
  - Microwave and laser systems also have limitations linked to weather conditions and their ranges *(see in sections 4.2.4.2.3 to 4.2.4.2.6)*
  - Interferences of other systems such as radio reference systems, wind sensors, and communications may happen when the vessel is too close to another one.
- In addition to disturbing the taut wire, down-lines can snag divers, or be broken and be driven into the propellers. For this reason, they must be negatively buoyant and provided with a "breaker" at their end. This breaker must be designed such that it is half the resistance of the down-line. Such small ropes must never be passed in double. Also, Down-lines should be installed only in the areas indicated in the work plan, and handled by experienced people who follow the instructions of the diving supervisor. Such arrangements and procedures are to be organized during the project preparation.
- Divers' umbilicals can be caught by debris or entangled with structures. For this reason, their deployment must be studied during the preparation of the project to avoid obstruction between the worksite and the bell and ensure that the divers will not be injured in case of a pull-off resulting from a sudden loss of position of the ship. Also, IMCA says that when the depth of the worksite puts the diver beyond physical hazards identified by the risk assessment and no restriction on umbilical length is necessary other than consideration of bail-out capacity, then an in-water tending point may be considered to enhance the safety of a working diver who is using an extended umbilical, accessing a structure or working within a jacket structure or manifold.
- It often happens that the divers need to fasten themselves to the structures they are working on to have more stability and not be obliged to fight the currents. In such cases, a "weak link", similar to the model recommended in IMCA D 058, should be used to protect them from a sudden pull off due to the vessel losing position. Note that IMCA says that the means by which the diver's umbilical is prevented from coming into contact with a hazard should not be dependent on this weak link.
- Emergency procedures in place to rescue and recover the divers and the bell/basket are based on those that should be in place when working from an anchored vessel and explained in book #4. However, they should be updated and be adapted to the working conditions and the vessel specifications, Also, a training program should be implemented.

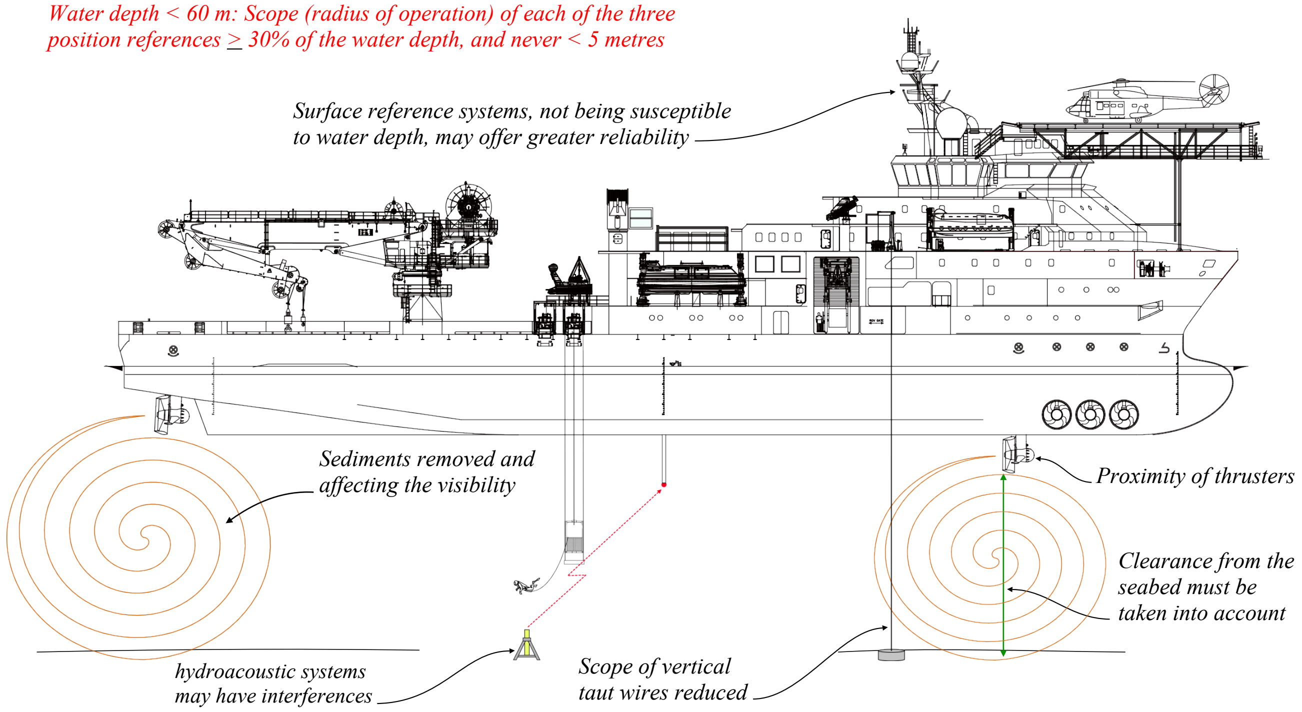
4.4.2.2 - Additional elements to take into consideration for operations in shallow waters

Diving operation in shallow waters have limitations linked to:

- The draft of the vessel and its minimum safe clearance from the seabed, taking into account that thrusters may be deployed below the keel.
- The depth of deployment of hydroacoustic poles, if used.
- The depth needed to deploy the bell/basket and its clump weight.

- The proximity of propellers and sea-chests that are permanent dangers to the divers. Also, their proximity to the seabed may affect the underwater visibility or increase their wash effects, which may disturb the communications of the divers and the acoustic reference systems. Regarding these points, note that the calculations of umbilical lengths are already discussed in detail in the previous points. Also, when vessels are equipped with retractable thrusters, the possibility of not using them when they are very close to the seabed should be taken into account. However, deselecting or isolating a thruster can only be decided by the vessel master. The risk assessment should take into account the reduced thrust capability of the vessel that should remain within the Activity Specific Operating Guidelines (ASOG). Also, the thruster unit which have been deselected must remain stopped and isolated as long as the divers are in the water.
- The effects of bad weather conditions that are increased by the proximity of the seabed. Note that it is also the case of current that may be violent and change direction according to the tide, particularly in estuaries and in areas of high amplitudes.
  Regarding this point, IMCA says that the vessel's capability plots may not accurately give the limiting environmental conditions for shallow water and operators should expect higher thruster and generator loads than for the same wind speed in deeper water and, as a consequence, termination of diving support operations earlier than might otherwise have been expected.
- The height of the tides that may affect the possibilities of escape, or make the vessel vulnerable to underwater structures or reefs, particularly in areas of high amplitudes.
- The accuracy of the underwater reference systems that are reduced. It is the case of the taut wire, which amplitudes are limited, and hydroacoustic systems that may have interferences due to the increased thruster wash. Regarding the procedures to solve this problem, IMCA says that each of the vessel's position references should provide position information accurate to ±2% of the water depth. For example, in 30 m of water, the information provided by the reference systems should have a standard deviation of ±0.6 m. Also IMCA recommends the following:
  - There should always be at least three position reference systems on line of which one should be a radio or surface position reference.
  - When working in water depths of less than 60 m the scope (radius of operation) of each of the three position references should be equal to or greater than 30% of the water depth, and never less than 5 m for example water depth =30 m, radius of operation 9 m.
  - Surface reference systems, not being susceptible to water depth, may offer greater reliability. These may, however, have limitations, the acceptability of which should be assessed, for example the Artemis range may be too great for accurate bearing resolution (The standard deviation of the vessel's natural excursions should not exceed one third of the scope of any position reference.)

The elements listed above should be taken into account for the preparation of operations in shallow waters and added to the elements indicated in the previous point



4.4.2.3 - Additional elements to take into consideration for operations inside subsea structures

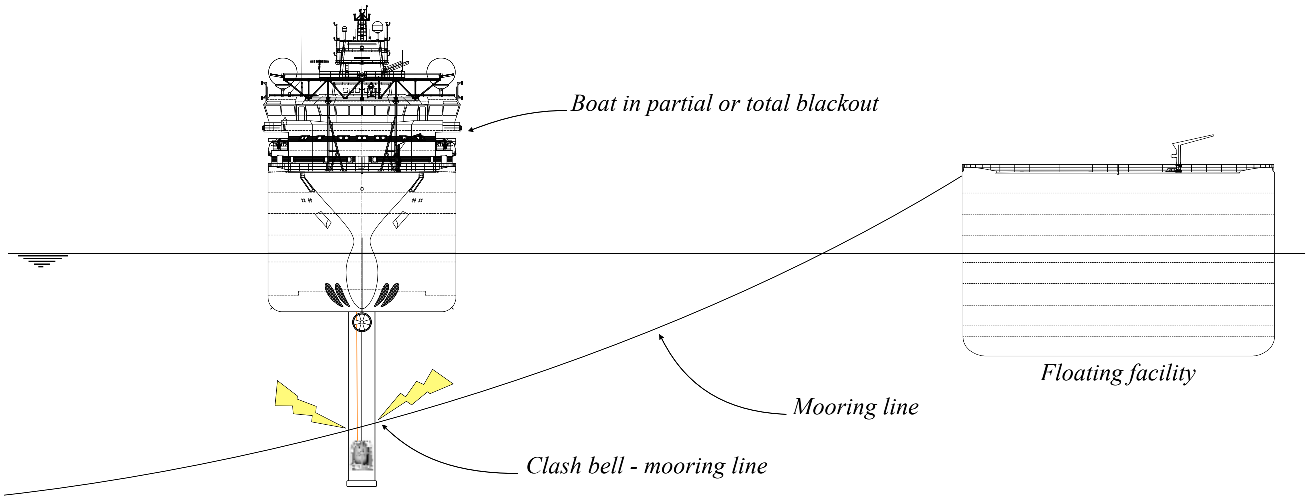
Note that enclosed subsea structures include constructions such as wellheads, Pipe Line End Manifolds (PLEM), and also jackets and platforms.
Entering into confined spaces is not recommended when diving from Dynamic Positioning vessels, as a loss of position of the diving support vessel may lead to a catastrophic event if the diver is stuck inside the structure he is working.

However, such operations may be authorized if appropriate means to ensure the safety of the diver in case of vessel failure are in place. For this reason, a lot of clients require that such operations are performed from a class 3 vessel, or some others require an increased number of reference systems. Also, specific procedures must be implemented for the deployment and the recovery of the divers:

- The structure should be precisely recorded in the operational plot, and its location should be verified by ROV or divers before starting the operations.
- The location and depth of the bell/basket and its clump-weight should be evaluated prior to starting the operations taking into account:
    - The height and the design of the subsea structure and the entry points available to go inside it.
    - The limits given by the mix used and decompression table.
    - The prevalent and actual environmental conditions on site.
    - The vessel’s position reference systems available and its capacity of holding the position within a reduced foot print.
    - The escape way of the vessel in case of a failure and its alignment with the entry point to go into the structure, to ensure that the umbilical of the diver is not stuck or cut in case of a loss of position.
    - The possible leakage of hydrocarbons or other harmful substances. Note that if such risks exist, the wet bell is to be positioned to the side of the structure to prevent the prevailing current from carrying any such substances into it. Also, adequate individual protection should be provided to the divers in addition to a protocol to enter the dome.
- Procedures for the management of the umbilical should be reinforced:
    - Sufficient umbilical length should be provided to allow for minor vessel movement.
    - The diver entering into an enclosed structure should be tended at the entry point by a second diver.
    - During the operations, the underwater tender at the entry point of the structure should ensure that the diver inside the structure can escape from it in case of a sudden movement of the vessel:
        - The umbilical of the diver is away from debris that can damage and catch it.
        - The diver is in the direct line to the entry point.
        - The umbilical of the diver is not in one of the corners of the structure that may trap it and the diver while the vessel is pulling.
        - The umbilical inside the structure should be actively tended. Nevertheless, there should be some slack available at the entrance of the structure to allow for the tender managing the vessel movements.
        - The tender should check his umbilical as well.

4.4.2.4 - Additional elements to take into consideration for operations within an anchor pattern

Diving operations within an anchor pattern are restricted by the presence of the mooring lines to which the bell can be entangled, and the presence of the anchored vessel to which they converge as a funnel. When diving operations are undertaken inside such an anchor lines pattern, the recovery of the divers and of the bell/basket have to remain feasible at all times because the vessel may suffer a partial blackout, which may result in drifting it towards anchor lines. If the bell/basket is not recovered in time, divers' lives can be at risk.



In addition to the clashes of the bell/basket with the mooring line note that incidents such as the collision of the boat with the facility, or The ROV entangled in the mooring lines may happen.
For the reasons indicated above, a lot of clients restrain human-crewed diving operations in their anchor patterns to a minimum. Also, They request that additional precautions such as those described below are enabled:

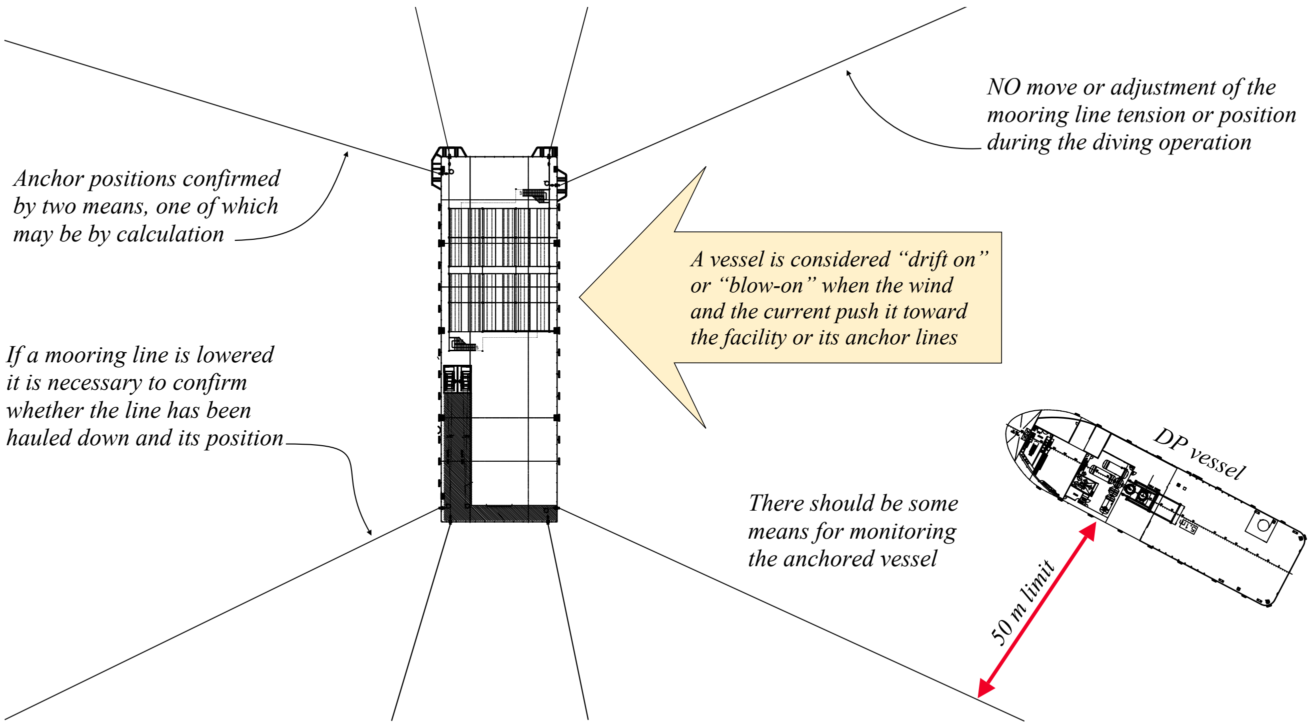
- Class 3 Dynamic Positioning vessels are mandatory with a lot of companies.
- The anchor positions must be confirmed by the moored vessel, and the location of the mooring lines must be controlled by two independent means, one of which may be by calculation. Underwater inspection and positioning of the mooring lines are usually performed with a Remotely Operated Vehicle (ROV).

Note that the configuration of the mooring lines should be clearly indicated in the working documents and updated on the nav screen.

- The positions of the anchors and mooring lines are valid only one time. It is necessary to recheck these positions in the case that another operation is to be performed in the same anchor pattern later.
- It may happen that a mooring line is lowered to the seabed to facilitate the operations. In this case, it is necessary to confirm whether the line has been hauled down and its new position. Also, reducing the tension of a line may change the stress and the location of the other line that must be checked as well.
- Communications must be in place between the Diving Support Vessel and the anchored facility. Also, there should be some means for monitoring the anchored vessel available to the Dynamic Positioning operators. These means can be radar or laser systems that permanently inform of the distance of floating facility to the DSV.
- When the positions of the mooring lines have been confirmed, they must be frozen for the duration of the diving operations. If readjustment of the lines or the draft of the moored facility is necessary, the master of the Diving Support Vessel must be informed first, and the crew of the moored facility must wait for the recovery of the divers before starting any action. The intention to readjust the lines must be immediately communicated to the diving supervisors, the Offshore Construction Manager, and the client representative on site, and the dive ongoing must be stopped. Then green light to carry on is communicated to the moored vessel. The dives can resume again after a new inspection of the lines and the evaluation of their new catenaries.
- In case the divers have to work on the seabed at the proximity of the touch-down point of a mooring line, precautions to avoid having them caught under the line or having their umbilicals entangled into it should be implemented. If possible, studies should be performed to having the boat oriented to escape from the anchor pattern when the dive is carried out on its edge.
- IMCA says that A horizontal clearance of at least 50 m should normally be maintained between a suspended mooring line and a deployed bell or basket. This nominal distance of 50 m in a “drift on” situation would, in most circumstances, be inappropriate.
  A Diving Support Vessel is considered “drift on” or “blow-on” when the wind and the current push it toward the facility or its anchor lines. In the case of a position loss, there may be a collision with the facility, or the closest anchor line can catch the bell. Note that the Dynamic Positioning Committee says that “even for a vessel operating in DP class 3, the risk of position loss cannot be disregarded”. For this reason, a safe distance that takes into account the time to recover the bell/basket above the lines is calculated:
    - Several recovery drills of the divers to the bell/basket cumulated to the recovery of the bell/basket to the surface must be undertaken. These exercises should be used to evaluate the time that is necessary to recover the bell/basket with sufficient clearance above the lines.
    - A vessel drift test should be performed before entering into the anchor pattern and compiled with the recovery time of the bell/basket to see whether the travel distance allows for the safe recovery of the bell/basket above the mooring lines or not. If the safe recovery is not possible, the dives must not be started.
    - If the drift test is satisfactory, the operations can be resumed. Note that new DP systems, such as an example the K-Pos DP system Kongsberg, provide predicted drift-off and drift-on paths at constant intervals of two to four minutes. Dynamic watch circles are displayed together with the Dynamic Operability Envelopes allowing the operator to position the vessel relative to the target in an optimum way while maintaining required safety margins *(See in the photo below)*.

- When the first dives are undertaken, several recovery drills of the divers should be performed to ensure that the recovery time calculated is adequate. If it is not the case, corrections should be entered into the software. In case that the new predictions of the software indicate that the safe recovery of the divers is not possible, and so the vessel is outside the Activity Specific Operating Guidelines (ASOG), the dive must be halted and the divers recovered as soon as possible.
- Note that during the operations, the divers must be recovered as soon as possible in case of a warning from the DP console. For this reason, recovery drills should be undertaken at regular intervals

- Note that maintaining a vessel in an anchor pattern using ropes attached to another DP vessel is not an acceptable practice. Thus, when the vessel is outside Activity Specific Operating Guidelines (ASOG), the operations are merely stopped, and the vessel must standby for favorable conditions to reenter into the anchor pattern. Note that IMCA M 185 "*Considerations about the use of hold-back vessels during DP diving operations"* has been withdrawn and not replaced.
- Regarding the selection of the reference systems, and as indicated before, taut wires may come into contact with the mooring lines if the vessel is very close. The selection of the reference systems should be performed according to the specifics of the worksite. However, IMCA says that if it is technically feasible, a radio or surface position reference should always be used.



4.4.3 - Vessel preparation

4.4.3.1 - International Maritime Organization (IMO) operational requirements

IMO says:

- Before every DP operation, the DP system should be checked according to applicable vessel specific location checklist(s) and other decision support tools such as ASOG (Activity Specific Operating Guidelines) in order to make sure that the DP system is functioning correctly and that the system has been set up for the appropriate mode of operation.
- During DP operations, the system should be checked at regular intervals according to the applicable vessel-specific watchkeeping checklist.
- DP operations necessitating equipment class 2 or 3 should be terminated when the environmental conditions (e.g. wind, waves, current, etc.) are such that the DP vessel will no longer be able to keep position if the single failure criterion applicable to the equipment class should occur. In this context, deterioration of environmental conditions and the necessary time to safely terminate the operation should also be taken into consideration. This should be checked by way of an automatic means (e.g. consequence analysis).
- The necessary operating instructions should be kept on board.
- DP capability polar plots should be produced to demonstrate position keeping capacity for fully operational and post worst-case single failure conditions. The capability plots should represent the environmental conditions in the area of operation and the mission-specific operational condition of the vessel.
- The following checklists, test procedures, trials and instructions should be incorporated into the vessel-specific DP operations manuals:
  - Location checklist *(see the 1st paragraph)*.
  - Watchkeeping checklist *(see the 2nd paragraph)*.

- DP operating instructions *(see fourth paragraph)*.
- Annual tests and procedures.
- Initial and periodical (5-year) tests and procedures.
- Examples of tests and procedures after modifications and non-conformities.
- Blackout recovery procedure.
- List of critical components.
- Examples of operating modes.
- Decision support tools such as ASOG (Activity Specific Operating Guidelines).
- Capability plots *(see filth paragraph).*

4.4.3.2 - Dynamic Positioning personnel on duty

Note that the competencies and number of persons on duty is also discussed in section 4.3.4 “Training and competencies of personnel”. However, to clarify the minimum crew on duty during the operations, note the following:

- Two Dynamic Positioning Operators, capable of operating the system both in DP and manual control without supervision, should be present in the Dynamic Positioning control station on bridge. The Dynamic Positioning committee says that they should have 3 years experience of a vessel engaged in similar operations, at least 6 months of which should have been on the subject or sister vessel. One of them should hold an appropriate deck officer qualification to be in charge of the navigational watch.
  Note that the Dynamic Positioning committee says that the Master should not be considered as one of the required unlimited DPOs for meeting the manning requirements.
  The period of time for which each DPO operates the DP control system should be limited to avoid loss of concentration. For this reason, it is usual that they relay every two hours.
- At least one licensed engineer, with at least 6 months experience on similar equipment and operations, and familiar with the operation of the power plant and the functions of the power management system, should be available at all times, and should be on watch during critical activities.
  Also, appropriately trained technicians, capable of minor fault finding and maintenance of the DP system, should be available at all times as long as the vessel is on DP mode. Some of them must be on watch to control the engine.
  Note that it may be required that an electrician has appropriate high voltage certification, if applicable to the vessel. As with vessel engineers, the electrician/electrical engineer should have at least 6 months experience on similar equipment and operations.

4.4.3.3 - Dynamic Positioning preparation trials and checks

4.4.3.3.1 - Pre mobilization trials:
These trials that are part of the pre mobilization process of a new project are usually carried out by the vessel’s crew. They are less rigorous than those of the annual DP trials but more stringent than the field arrival checks. They must confirm the vessel’s redundancy concept and station keeping performance after worst-case failure. They must also provide assurance of the integrity of the DP system of the ship and her operational limitations.
Generally, these trials are monitored by a marine specialist mandated by the client.

4.4.3.3.2 - Oilfield arrival checks:
These checks must be carried out upon arrival at the field, and outside the 500 m limit and maybe at a greater distance if required by the onsite manager. Note that the vessel cannot be authorized to enter into the 500 m limit as long as these tests are not successfully completed.
The purpose of these checks is to ensure that the DP system, thrusters, power systems, and others work satisfactory and that the set up of the DP system is correct.
Note that the drift test indicated in section 4.4.2.4 is to be performed at the end of these checks when the vessel is planned entering into an anchor pattern. Also, drift tests may be required by the client for other types of operations.
The onboard client representative usually monitors these trials.

4.4.3.3.3 - Worksite arrival checklists:
These checks should be carried out when the vessel arrives in the position above the worksite. Their purpose is to confirm that the ship is appropriately set up and the elements previously tested work satisfactorily, taking into account the limitations of the position reference.
Regarding this point, ADCI says that in addition to the successful completion of these checks, the vessel must hold station automatically within the defined degree of accuracy until the master and senior diving supervisor are confident that the system is reliably set up before diving operations are permitted to start. That may take at least 30 minutes.
Note that the beginning of the 30 minutes station keeping test must be noted by the diving supervisor and he DP officer.
The onboard client representative also monitors these trials.

4.4.3.3.4 - Pre-dive checklist:
When the 30 minute station keeping test is completed, a series of checks must be performed prior to commencing diving operations. These tests consist to verify that all the visual and audio alarm devices and the main and back up communications are working accurately.
Once these tests are successfully completed, the DPO turns-on the green light of the visual alarms to notify the supervisor that he can launch his dive.

4.4.3.4 - Dynamic Positioning checks performed during the dive

4.4.3.4.1 - Six Hours Status Checklists:
The Diving Positioning Committee say that the purpose of these checks is to record the status of the DP system and configuration. The checks should verify that the vessel's station keeping performance at the working location is satisfactory and, in particular, that the position reference systems are properly set up and operating satisfactorily. No testing is carried out for these checks. The Dynamic positioning Operators should complete the checklist prior to taking over the watch, not during the first few minutes of the watch.

4.4.3.4.2 - Engine control room checklists:
The engine room staff must perform checklists at regular intervals during the operations and keep the DPO on duty informed of the status of the machinery and of any abnormalities that may affect DP operations. Note that it is obvious that these people check the system for all the checklists and trials listed above.

4.4.4 - Elements to take into consideration for vessel movements during the dives

Usual procedures to change of position on the worksite is to recover the divers in the wet bell or the basket, and then to slowly move the vessel to the next location. This procedure is standard when it is necessary to move the divers to a not distant target that is outside the limits of their umbilicals.
However, when the divers are working on a target that necessitates performing long moves, it is often preferable to relocate the vessel instead of giving the divers the maximum allowable umbilical lengths. Also, the Dynamic Positioning Operator may need to readjust the heading or the position of the ship slightly. In such cases, it is common to execute some limited vessel moves without recalling the divers to the bell. The procedures employed are usually based on the one promoted by IMCA provided that the following precautions are in place:

- The Dynamic Positioning vessel is stable and under the full control of the operator.
- The weather conditions allow performing the operation safely.
- Three position reference systems must be online throughout the move.
- The readjustment of the vessel must be organized such that a change of heading and position are not executed simultaneously.
- During the travel, the vessel must not exceed the scope of any one of the three position reference systems. The action must be stopped when any one of them has to be repositioned.
- The DPO and the diving supervisor agree with the move to perform. Also, both of them can stop the operation at any time.
- The move to be performed is identified, and the parameters to execute it safely are entered in the DP system.
- The divers are not far from the bell that can be easily reached. They must be able to be recovered to it at any time.
- The divers are informed of the move to perform and understand it. They also have the power to stop the operation at any time.
- The umbilicals of the divers must be clear and be actively tended during the move.
- The operation can start only when the divers are in a safe location and ready to proceed.
- The move must be executed slowly.
- The DPO must inform the diving supervisor when each phase of the move starts and when it is completed. Such information must be communicated to the divers.

5 - Diving from facilities and self-elevating units

Diving operations from facilities such as jetties, production platforms, and others impose the same rules as working from boats or barges. However, it must be kept in mind the fact that some of these facilities can be in exploitation, which may oblige to implement specific procedures that may be disturbing for the diving team and finally counter productive, or may oblige to stop the other normal activities of the installation for the duration of the dives. For these reasons a close study of the advantages and inconveniences of organizing such operations must be undertaken.

5.1 - Considerations for diving operations

The following elements should be taken into account for organizing diving operations:

- A risk assessment should be made to identify the potential hazards which could impact the planned diving operations and whether some of them may trigger abandonment of the installation.
  Using this risk assessment, the project team must consider whether the project is feasible, and if it can be undertaken while the installation is fully operational or whether the regular operations should be halted while the diving project is in progress. For such an evaluation, The "hazardous areas classification" indicated below must be considered. Note that the operator has to report which parts of the structure are under such classifications.

Zone	Definition	Description	Areas specifics
Zone 0	An area is which a hazardous atmosphere is continuously present.	- Zone 0 classification applies to the internals of process vessels, storage tanks and other similar closed containers. - Any source of ignition in a Zone 0 area would, almost certainly, lead to a fire or explosion	- Please note, hot work is not allowed at any time in Zone 0 or Zone 1 areas. - Because of the presence of hydrocarbons, and the risk of explosion and fire, diving operations cannot be undertaken in zone 0 and 1. - To be acceptable for diving, the area classified as Zone 0 or 1 must be shut down, isolated, depressurized and cleaned, such that the hazard which caused the area to be classified as Zone 0 or Zone 1 is removed for the duration of the work.
Zone 1	An area in which a hazardous atmosphere is likely to occur during normal operating conditions	- Zone 1 classification applies in production areas around process vessels, wellheads, open drains, vents etc. and in all areas where gas is used as the drive material for instruments	
Zone 2	An area in which a hazardous atmosphere is not likely to occur during normal operations.	- Explosive atmosphere is for less than 10 h/year, but still sufficiently likely as to require controls over ignition sources. - In addition to ignition, hydrocarbons are a direct danger to the health of the personnel.	- The control measures over ignition sources must be implemented . - The precautions include fixed & portable gas detectors, audio and visual alarms, breathing apparatus & respiratory escape devices. - There must be a means of escape from the work site, and a refuge at direct proximity. - The dives with decompression can pose a problem of escape and should be minimized.

- The installation of the diving system must follow the same rules as for working from a boat. Thus similar practices such as fastenings inspection and load tests have to be performed.
- The access to the facility and the problems which could be posed by the installation of the diving system must be evaluated closely:

- Installing the system too low can expose it to the waves with no possibility to escape the bad weather. Installing it too high can create an additive hazard, such as the risk of falling at sea increased by the height from which the person is dropping. Also the duration of the recovery of the deployment device from the surface of the sea must be taken into account and minimized.
- Also, the system may have to be installed in areas at the direct proximity of other activities that may be sources of hazards, in addition to the fact that the working zone may be congested. Protections against events such as, but not limited to, mud projections from drilling operations, lifting operations above the dive station, unauthorized personnel crossing the dive station, and others should be organized.

- Electrical supply can be complicated and may oblige the use of generators that are far from the station. That may oblige organizing for people standing by at their proximity during the operations in case of a breakdown. Also, generators must be located in non-hazardous areas. A properly installed and maintained spark arrester that can reduce fire and explosion by trapping the exhaust particles may be mandatory to all thermal engines. Homemade spark arrestors are not acceptable.
- Note that the dive control and machinery rooms should be outside areas where explosive and harmful atmospheres are likely. Also, the client may impose the use of pressurized dive control and machinery rooms in case gas release may happen.
- Another problem is the safe transfer of equipment to these areas that may be complicated. Also, whether the personnel operating the system must be able to access the station without being exposed to hazards arising from the normal activities of the facility. Besides, note that it may happen that the dive system has to be transferred to another part of the facility when several phases of projects are planned.
- The emergency evacuation of the people in the event of failure of the normal evacuation arrangements must be in place with MEDEVAC as well. Training of the diving team should be organized for MEDEVAC and abandonment of the site.
- Procedures for simultaneous operations should be implemented if the facility is active. Also, the diving interventions may have to be interrupted in case of conflicting activities.

- Reliable means of communications, similar to what is normally in place on boats have to be installed:
  - Main and back up communications to the radio room of the facility, or when working on a quay the people who manage it.
  - Main and back up communication to the client representative and the area authority.
  - A reliable dedicated system of alarm installed in the dive station in case of fire and abandon of the facility.
  - Protection from boats transiting in the vicinity must be enforced:
    - The Alpha flag visible. Sometimes it is necessary to install more than one.
    - The lights indicating the work-site applies the same rule.
    - When working on jetties, facilities close to the shore, and zones of traffic, there must be warning buoys, flashing lights, audio warnings (loud speakers), and small patrol boats to warn and push away the vessels and the small fishermen which may sail or fish at proximity. The team must also be briefed and trained to respond quickly to these dangers.
    - The radio operator of the facility must be trained to apply the rules linked to diving operations. He must be sufficiently experienced and “bossy” to manage and keep away the boats that may have to cross the safety area.

Because they do not respect any maritime rule, the small fishing boats are a hazard difficult to manage when diving from a facility.
A preventive system must be in place to ensure that they will not go in the vicinity during the diving operation.

5.2 - Additional considerations for surface orientated diving operations

Note that surface orientated diving may be used to rescue a bell near the surface. That can also be possible at depth if the saturation operations are performed at depths that are reachable to divers deployed from the surface.

- IMCA D 025 says that there must be particular attention to the recompression facilities, which should be located in an appropriate position to facilitate the safe escape of diving personnel in the event of an emergency. Also, note that in case that dives with decompression are planned, this chamber must be reachable within limits indicated in the decompression table in case that planned or emergency surface decompression is to be performed. That means that even though the decompression planned is in the water, surface decompression must be available at all times.
  In complement, when surface supplied diving is to be organized from an active installation, decompression should be minimized or forbidden in the case that the environmental conditions cannot always be under control and that events such as harmful or explosive gas release or a fire may happen and trigger abandonment of the site.
- In addition to the decompression chamber on site, there must be an alternative decompression facility within a reasonable travelling distance from the dive site.
- Gas reserves conform with IMCA D 051 should be connected or at the immediate proximity of the system.
- There must be a means of recovery of a diver adrift at the surface, or personnel fallen at sea.
- The signalization of the work-site must be clear and visible, particularly when working at close proximity to the shore and areas of traffic

6 - Diving with Remotely Operated Vehicles (ROV)

6.1 - Purpose

Remotely Operated Vehicles (ROV) have been developed since the end of the sixties. They are used for any kind of tasks such as the inspection of the seabed or structures, the maintenance, and the construction of facilities, the research of wrecks, the rescue of submarines, and others.
Because they are uncrewed vehicles, they are commonly used to access areas that are not reachable by divers, or for operations where there is a risk to harm them. In parallel to these activities, they are used for diving support tasks such as the inspection of the worksite and the bell, the surveillance of the divers and their surroundings, bell rescue, and others. So, they are today considered indispensable for the monitoring of such operations.
However, depending on the model used, ROV diving support activities may expose divers to potential problems such as for an example:

- Entanglement of the umbilical of the ROV with those of the bell or divers.
- Injury to a diver through collision, propellers, or Electrical shocks.
- Obstruction of the escape way in case of a loss of position of the vessel.

For these reasons, a detailed risk assessment must be carried out to prevent or minimize these potential problems before launching the bell. Nevertheless, to be efficient and not unnecessarily restrict the use of this tool, it is crucial to have a minimum knowledge of it and of the rules that have been put in place by organizations involved with diving operations.

6.2 - ROV classifications

A lot of diving and ROV organizations identify Five main classifications of Remotely Operated Vehicles (ROV), which are those established for a very long time. They remain the main ones, despite that the industry made a lot of new hybrid products that cannot be formally classified in one of these categories.

Class 1 - Pure observation

Pure observation vehicles are physically limited to simple video observation tasks. They cannot undertake any other task without considerable modification and are usually very small machines that can be carried by hand.
The machine in the illustration is a "Seabotix LBV150".

Class 2 - Observation with payload options

IMCA classifies "class 2A" the vehicles that are capable of carrying additional tools such as cathodic protection measurement systems (CP), additional cameras, sonar systems, small manipulators, pipeline and cable detectors, etc… They are capable of operating without loss of their original function when carrying at least two additional sensors.
IMCA classifies "class 2B" the vehicles capable of carrying the same equipment of class 2A plus light working manipulators and tooling skids to be able to perform light construction support, intervention and survey tasks.
The machine in the illustration is a "Seaeye Cougar XTi".

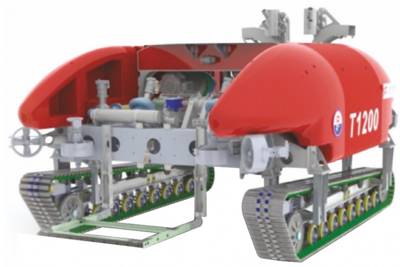
Class 3 - Work-class

These vehicles are large enough to be fitted with additional sensors, and special tools, and have at least two manipulators.
They should have a multiplexing capability allowing additional sensors and tools to be operated without being hard-wired through the umbilical system. Also, the umbilical should have spare conductors to allow operation of payload equipment.

- IMCA classifies Class 3A the machines with less than 200 kg payload and 100 kW power. We can call them "light work class"
- IMCA classifies Class 3B the machines with at least 200 kg payload and 100 kW power. We can call them "Heavy work class"
- Note that NORSOK U 102 uses a similar classification.

The machine in the illustration is a "Forum Perry XLC-C" *(Class 3B Imca)*.

Class 4 - Towed or bottom crawlers



Towed vehicles have no propulsive power, although they may be capable of limited manoeuvrability. They travel through the water by the hauling action of a surface craft or winch.

Bottom crawling vehicles move primarily by exerting ground pressure on the sea floor via a wheel or track system, although some may be able to “swim” limited distances.
These vehicles are often used for the detection or the burying of electrical and communication cables and similar tasks.
The machine in the illustration is a “Forum Perry XT 1200”.

Class 5 or IMCA class 5 and 6 - Autonomous Underwater Vehicles (AUV) and prototypes

IMCA separates these vehicles into two classes: Class 5 for prototypes, and class 6 for AUV. Other organisations use one class only.

Prototypes are vehicles specially designed for a particular project that cannot be classified as above and are not produced in series.

Autonomous Underwater Vehicles (AUV) are not linked to the surface by a tether and can work without requiring input from an operator. They are designed to run on very long distances.
These vehicles are used for tasks such as mapping, video imaging of targets, acoustic pinger searching, black box finding, etc.
IMCA identifies them into class 6A (< 100 kg) and 6B (≥ 100 kg).
The machine in the illustration is an “ECA A18D”.

Particular case of heavy observation class/ light work class

The classification given by IMCA and NORSOK does not provide any minimum performance to ROVs class 2B and class 3A, which results in difficulties in identifying them. To clarify this point, we can say that a "light work class ROV" has two manipulators, can be equipped with additional tools similar to those used by class 3B ROVs, a payload >100 kg & < 200 kg, a power equal or more than 100 kW, and vertical or horizontal thrusters delivering at least 100 kgf.
The machine in the illustration is a "Seaeye Panther".

Hybrid machines

These machines combine several technologies, such as those used for wired class 3 ROV with those of Autonomous Underwater Vehicles (AUV), or those of observation ROV with those of bottom crawlers.
An example of such products is the “ECA H-ROV” *(see the illustration on the right side)*, which is a class 3 ROV designed with an integrated power battery that allows for remote operations through a single optical fiber or fully autonomous intervention supervised through acoustic communication.
Such machines are used for remote or autonomous operations such as seafloor and relief survey, inspection, intervention on wrecks and structures.

Another example from the same manufacturer is a machine named “Rovingbat” *(see the photo on the left side)* that is an ROV designed to inspect and clean vessel hulls and that is provided with crawlers to progress on the support it is glued to by its thrusters. This machine can swim to its target as a normal ROV. Machines for similar applications are proposed by other manufacturers.

6.3 - Description of ROV systems

6.3.1 - ROV classes used for direct support of surface-supplied diving

Remotely Operated Vehicles (ROV) are commonly used to support surface-supplied diving operations. However, opposite for saturation operations performed with single bell systems, surface supplied diving operations are performed with a means of deployment of the rescue diver from the surface. For this reason, ROVs are not considered essential for such operations, even though they should be used to support them.

- Class 1 ROVs do not carry any tools and are not designed for payload. In addition, they are usually very small machines that are not powerful enough to fly in strong currents. They are used for observation only.
- Class 2 machines are designed for all types of inspections, but their payload is limited to less than 100 kg. Also, their power is limited, and some models have difficulties swimming through strong currents. Besides, their tools are usually fitted through an additional frame mounted below the machine and designed only for small tasks such as grabbing small objects and samples, performing small cleaning tasks, or manipulating inspection tools.
- Light work class ROVs are often found. They are cheaper and lighter than class 3-A & 3-B and can perform many tasks. They are powerful enough and sufficiently fitted to recover a wet bell.
- Work class ROVs are powerful machines often used to perform complementary tasks of the divers. They can also be used to rescue a closed bell, and of course, recover a wet bell

6.3.2 - Description of a Class 3 ROV

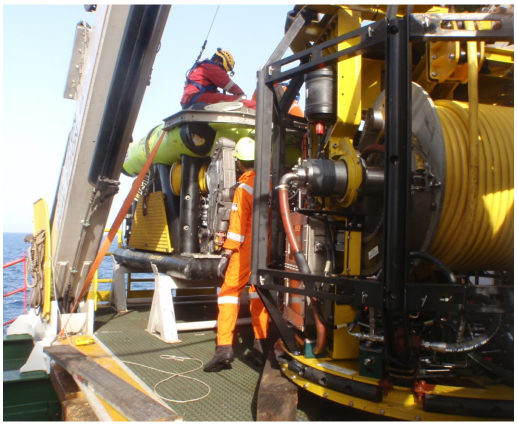
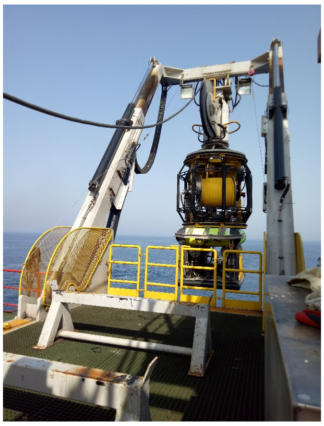
6.3.2.1 - Machine used for this purpose

Describing ROVs is not easy, and the best procedure for providing consistent descriptions is to refer to practical examples of machines that are among the most complex. For this reason, Class 3 ROVs are taken as reference, with a lot of explanations based on models, such as the Merlin WR 200, fabricated and exploited by IKM Subsea AS

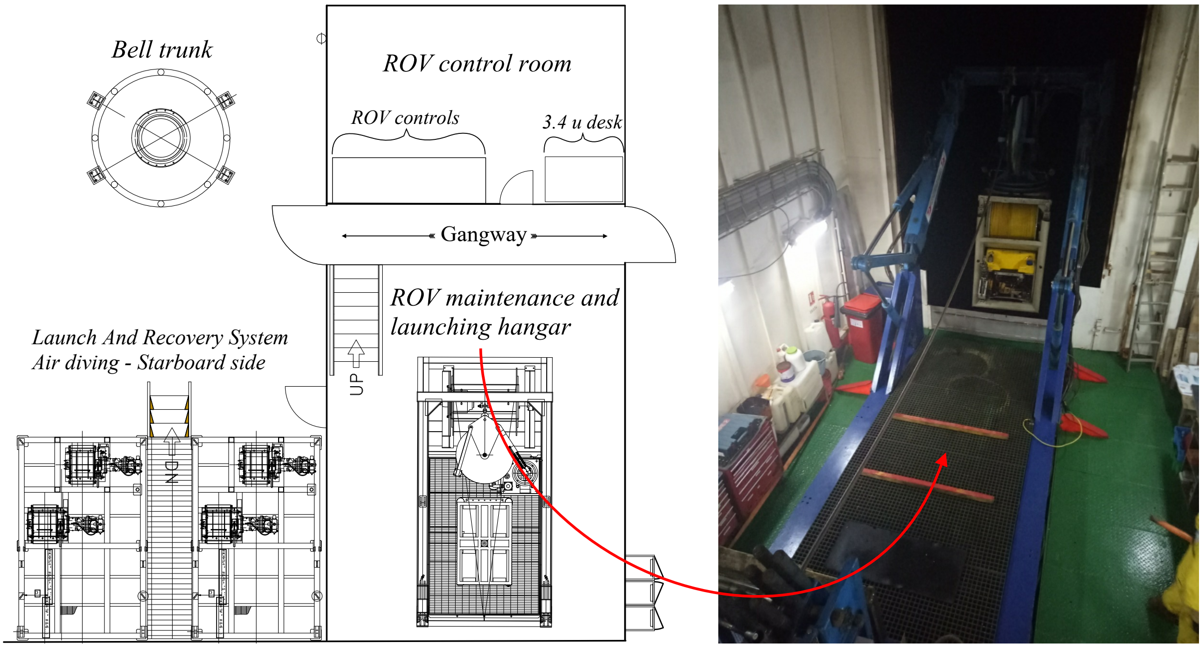
6.3.2.2 - Types of installation

Class 3 ROVs are massive machines whose weight varies between 2000 and more than 5500 kg. For this reason, they cannot be easily manipulated. Two types of installation are encountered that are similar to those of diving systems:

- Transportable systems are designed to be installed on any location sufficiently broad to accommodate them. The control room and electrical devices are protected in containers, and the launching and maintenance interventions on the machine are performed on the deck. Depending on the possibilities, the electrical supply is provided through the electricity supplied by the surface support, or by transportable generators.
  The advantage of such systems is that they can be installed on vessels of opportunity. Their main inconvenience is that the machine and the people intervening on it are not protected from the weather conditions.


- Integrated (built-in) systems are installed inside the vessel. The ROV is deployed from a hangar that is closed by a watertight door when it is not in use, so its deployment and maintenance are performed from a protected area. The inconvenience of such systems is that the replacement of some components can be complicated.

- Note that ROVs can be launched from a moon pool instead of the side of the vessel.

6.3.3 - Electrical supplies

6.3.3.1 - Power supplies

The main power supply of a work class ROV may be provided by the electrical system of the vessel (it is the case with built-in systems) or by customized transportable primary and backup generators (it is often the case with portable systems). Note that generators must be designed to work offshore and be equipped with spark arrestors and earth leakage protection, as described in section 2.22 “Generators” of Book #4.

The primary input is typically between 400 & 480 Volts/ 50-60 Hz AC, with power between approximately 150 & 380 KW, depending on the machine. As an example, the “Merlin WR 200” system needs 150 kW of 440V/50-60Hz.
Note that in addition to the primary input, an auxiliary input of 220 - 240 Volts is usually provided by the generators for domestic usages.

6.3.3.2 - Power Distribution Unit

The primary input is fed via a junction box to the Power Distribution Unit (PDU), from which it is spread to the elements that compose the ROV system, such as the Launch And Recovery System (LARS), the Tether Management System (TMS), the control room and consoles. Step up and step down transformers are used to adjust the current to the needs of the components listed above.

- A step-up transformer is a device in which the output voltage is higher than the input voltage. That is obtained by the use of more turns in the secondary wiring than the primary one of the device. The reason for stepping up the tension is to overcome line losses through the umbilical of the ROV. Note that power supplies of ROVs are commonly between 100 and 3300 volts AC.
- A step-down transformer uses the inverse principle of work of the step-up transformer to provide an output current with less voltage than the input supply. That can be used to adjust the current to some components. Also, some models of ROV may use low voltages current such as 160 volts AC.

6.3.4 - Control room

6.3.4.1 - Control and sensing systems

A lot of ROVs have their controls and displays grouped in only one control console. However, these elements are split with some last generation work class ROVs, so the pilot is sat in a comfortable armchair where all the controls are provided through joysticks and touch-screens installed on the arms of the seat, and are separate from the main displays.
Note that, the joysticks are usually analog systems that emit varying Direct Current (DC) signals of approximately 5 volts through appropriate resistors according to their position. These signals are then digitalized and multiplexed before being transmitted to the vehicle electronics through the umbilical. The commands operated from the touch screens are digital as they are directly processed through a computer.
To understand the difference between analog and digital commands, note that analog commands emit electric pulses of varying amplitude. Instead, digital systems emit signals into a binary format using zero or one, where zero represents an "off" state, one an "on" state, and combinations of these 1 and 0 are used to create messages.
Also, multiplexing is a method to combine multiple analog or digital signals into one signal over a shared medium.

A "two-way data link" allows transmitting the data from the control console to the vehicle and those from its sensors to the surface. These sensors consist of transducers that convert one form of energy, such as pressure, temperature, or

acoustic, to electrical signals. These analog signals are then converted to digital and transmitted in the same manner as the control signals. The information from the sensor is displayed to the pilot on the control console.
Note that the telemetry system works on the "master/slave principle", the surface electronics being the master, and the vehicle being the slave. As a result, if the vehicle power is switched on before the console power, a situation may arise whereby the slave is enabled but does not receive any command from the master unit, which may damage the telemetry system. For this reason, ROV pilots are taught to switch on the console power first, then the vehicle, and at last the hydraulic system, and to proceed in reverse order to shut down the system.
Video monitors that can be switched are used to show video pictures and information from sensors as required. Liquid Crystal Display (LCD) technology allows displaying video signals on large screens 45" where 17 "monitors were used previously with cathodic tube combos.

As an example of the description above, the Merlin WR 200 is provided with two pilot chairs and a separate desk/space for the supervisor. Large monitors on the wall display essential information regarding the condition of the machine during the operations. Also, the commands and touch screen controls are installed on the seat.

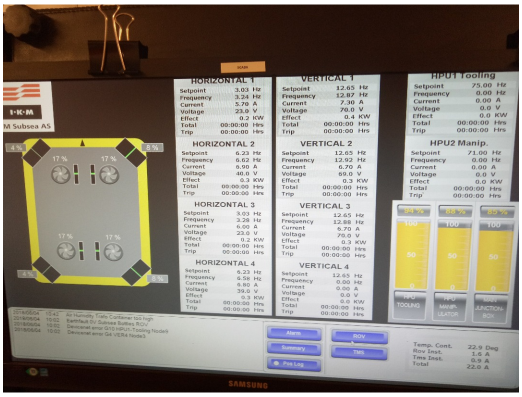
Microphone communications to bridge and dive control

Touch screen control

Control manipulator

Mouse control computer

Joystick control ROV



Display of the power used by the thrusters

As a comparison with the last generation machine above, the photos below show the control console of an ROV of the previous generation where cathodic screens are still used in parallel with LCD monitors. Note the analogic commands composed of classical switches and potentiometers that have been replaced by touch screens on the WR 200.

6.3.4.2 - Protection against harmful and explosive gasses

This system is provided with ROV systems designed to work where harmful and flammable gas releases are likely and within the 500 m limit of all offshore installations of some countries. Its function is to provide a pressurized safe area against these gasses by preventing their intrusion into the cabin and sensitive zones when the team is at work and stopping the machine in case of a failure of this protection.
When the system starts up, the fan of the Room Pressurization System (RPS) pressurizes the cabin to a pressure of approximately 0.75 millibars, and the gas monitoring system prevents any attempts to start the machine during a test period of approximately 20 minutes. If no gas is detected, the ROV can be switched on.
During the dives, the internal pressure of the cabin is maintained above a predetermined minimum pressure. Should it fall below this level (usually 0.25 millibars), the system automatically shuts down the ROV system to prevent the ignition of the flammable gas that may be present in the room atmosphere as a result of an electrical arc.

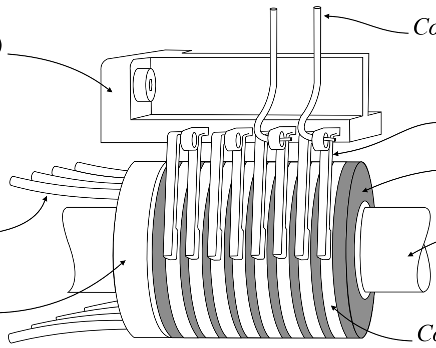
6.3.5 - ROV deployment systems

6.3.5.1 - Launch And Recovery Systems (LARS)

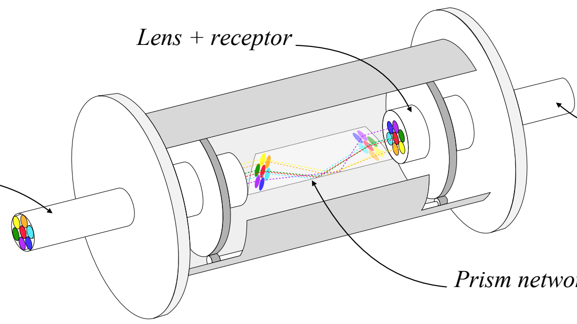
Work class ROVs can be deployed overboard and recovered using hydraulic cranes or 'A' frames.

These devices are powered by Hydraulic Power Units that are activated by a 3-phases 300 to 480 volts electric motor, the power for which is taken from the Power Distribution Unit (PDU).
Note that the umbilical that transmits power and data to and from the machine is also used as lifting cable with a lot of machines. In this case, the lifting strength is provided by a steel wire wrap that surrounds the umbilical.
The winch where this umbilical is stored is electro-hydraulic, and designed to provide the pilot with information such as the power delivered and the length of umbilical paid out. Some units are activated by the same Hydraulic Power Units as the jacks, where some others use a separate HPU. Also, to transmit the power and the information to and from the ROV, the system must be equipped with the following elements:

- The fixed junction box, which is a two way junction box that groups power, video signals, and data signals to and from the umbilical.
- The rotating junction box, which is attached to the main drum of the winch and carries out the same function as the fixed junction box.
- The slip rings provide interfaces between the fixed junction box and the rotating junction box. The unit consists of several contacts called brushes mounted on a fixed point above a small cylinder, and connected to the fixed junction box. The cylinder is coupled to the winch drum and rotates. There are several rings made of conducting materials installed around it and separated by isolating elements. These rings are connected to dedicated wires that carry the electricity and data to the rotating junction box. Thus, these rings make physical contact with the brushes attached to the fixed point. As a result, electrical continuity is maintained during the rotation of the winch drum *(see the drawing below)*. Note that some systems use a disc instead of a barrel, but the principle of contact is the same. These systems are called "pancake slip ring".



Also, light signals from the optic fibre must be transmitted as well. This is done through a prism network and then onto a lens that converges the light onto a receptor in the rotary section of the joint before it is sent down the umbilical. Slip rings used to transmit optic fibre signals are called "Fiber Optic Rotary Joints (FORJ)".



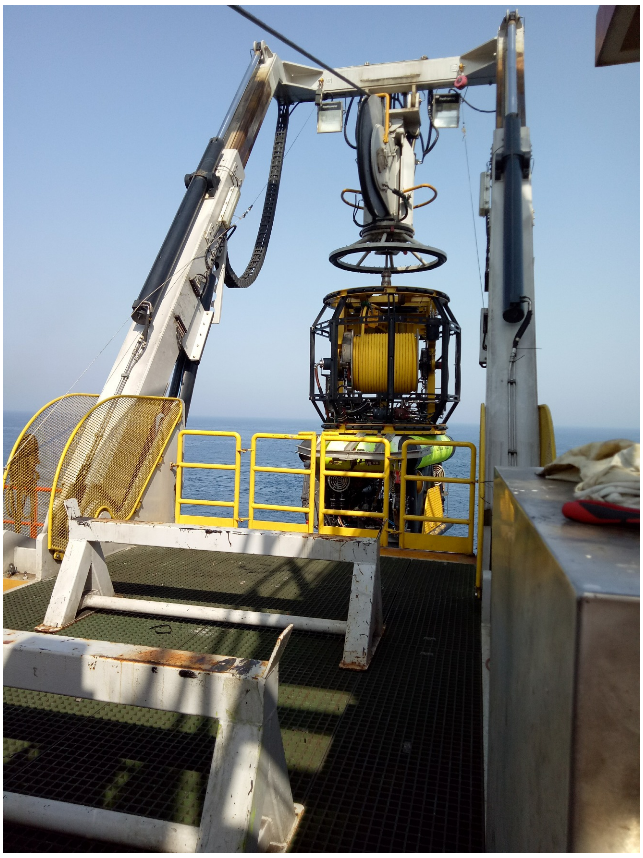
The cranes are usually provided with telescopic booms, which reduce their space on deck and increase their manoeuvrability. Also, the winch is mounted under their jib, so that it can pivot with it.
The deployment of the ROV using a crane usually consists of lifting it above the deck and then rotate the crane laterally

To lower the machine to the water. A latch allows releasing it when it is in the water *(see below)*.

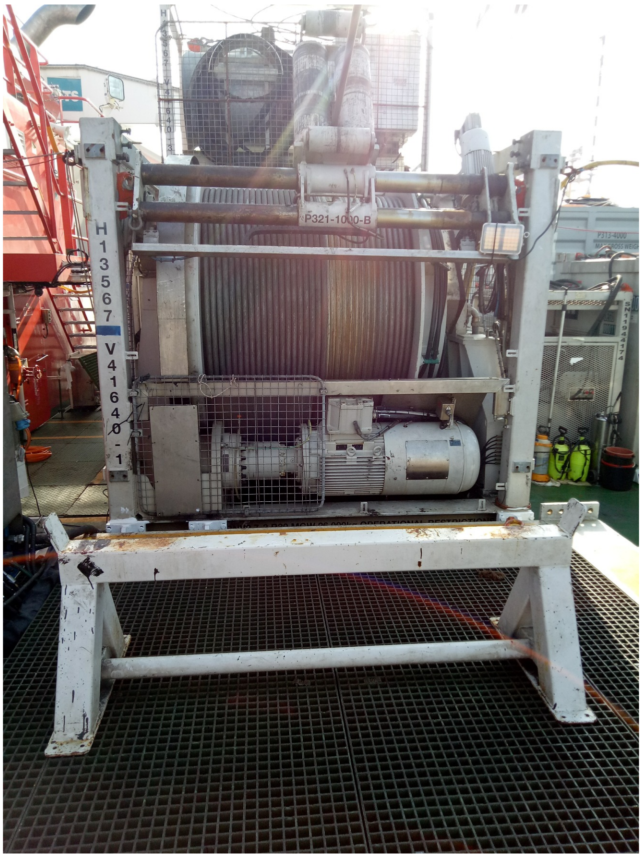
Crane starting to lower a ROV to the water (it is a old model). Note that the umbilical is not used to lift the machine.

Umbilical winch installed below the jib of the crane. Note that the wire winch is on the jib.

'A' frames cannot rotate laterally, so they only pivot to the front or the back to position the load above the water or return it to the deck. The winch is not integrated into the lifting frame and is bolted on the rear of the horizontal chassis on which the 'A' frame is mounted. Note that this system is found with most recent models and particularity those that are integrated into their surface support *(see the photos in* point 10.3.1.2 *)*.



'A' Frame deploying a WR 200 ROV. Note that the umbilical is used as lifting cable



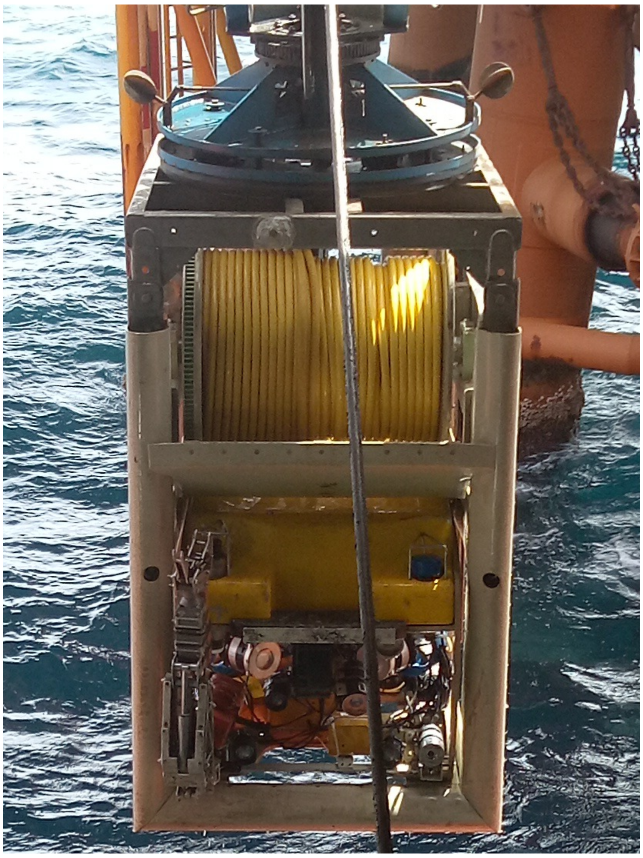
Winch of the WR 200 ROV installed on the rear of the horizontal chassis. Note the steel wire wrap of the umbilical.

6.3.5.2 - Tether Management Systems (TMS)

ROVs with the diving umbilical controlled from the surface are limited in depth and performances due to the drag factor resulting from the lengths deployed. To solve this problem, the vehicle is deployed from a "garage" hanged to the main umbilical of the LARS, and in which the reel of the "ROV umbilical" is installed. The ROV moves outside this garage only when arrived at depth. Thus, it is not impacted by the currents above it. The paying out and reeling in of the umbilical during the diving operation is done by what is known as a "Tether Management System (TMS)" that is controlled from the control room.

"Garage" types TMS are mostly used with small and medium units. Performing the maintenance of an ROV obliges the team to remove the machine from the cage and then reinstall it. Because such handling would be difficult and time-consuming with ROVs of several tons, these machines are often secured to the bottom of a tower called "Top-hat TMS", which contains the Tether Management System and which is hanged to the LARS through the deployment umbilical.

IMCA says that a TMS is mandatory for ROVs of class 2B and above, while a lot of clients request it for all machines.



Garage type TMS: Note the armoured lifting umbilical at the forefront, and the vehicle stored underneath its umbilical reel.

Top-hat type TMS: Note the fixation to the armoured lifting umbilical, and the mechanism of the system.

The TMS control signals pass down the armoured lifting umbilical in the same format as the ROV control signals. They are then processed by electronic systems in waterproof containers to control the appropriate hydraulic valves.
The ROV umbilical is housed on a hydraulically controlled drum. From this, the umbilical passes through a system of guides and rollers that maintain the correct tension on the umbilical whilst paying out and reeling in.
A pan and tilt camera is also fitted to the system to aid the pilot when latching and unlatching the ROV.

6.3.6 - ROV vehicle

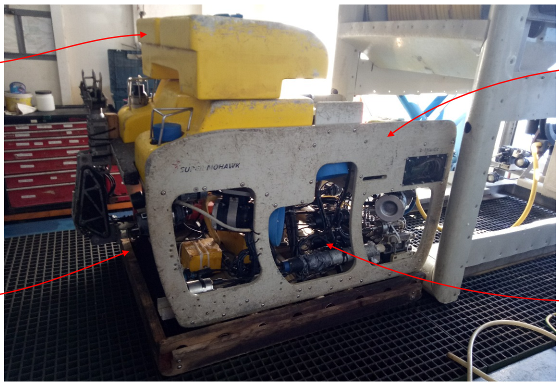
6.3.6.1 - Frame and buoyancy

The components which make up an ROV are assembled on a frame, usually made of aluminum, plastics, and composite materials.
The problems to solve for the conception of an ROV are similar to those of the aviation industry: Design a vehicle that is not too heavy to save power, and sufficiently strong to withstand the structural stresses from the working operations performed with it, and the effects of the pressure at the maximum depth it is planned to go. Thus, manufacturers usually look for materials that have an excellent weight to strength ratio and good durability. Vulnerable areas, such as the bottom frame, are fitted with replaceable skids of wood, plastic, or aluminum.

Usually, the ROV is designed with a neutral buoyancy that can be adjusted slightly positive or negative according to the needs of the team. Also, it is common that tools have to be added or removed. For this reason, the vehicle must be designed such that its buoyancy can be adjusted.
Modern ROVs designed to have payload are equipped with "hard buoyancy" components, which can be added or removed as required. These components consist of high-density foam that is injected into containers made with composite materials that protect it against water intrusion, shocks, and the crushing due to the external pressure. These containers are designed to fit the shape of the vehicle.

Hard buoyancy components (1 unit is removed)

ROV side made of plastic



Chassis made of aluminium

Openings to lighten the ROV and allow for easy maintenance

Note that some previous models of ROVs were fitted with air ballasts that were providing the possibility to adjust the buoyancy during the dive. However, this system is not usable at the depths last generation machines are designed for: Note that the external pressure at 3000 m is 300 bar, which is the maximum pressure of a compressed air cylinder.

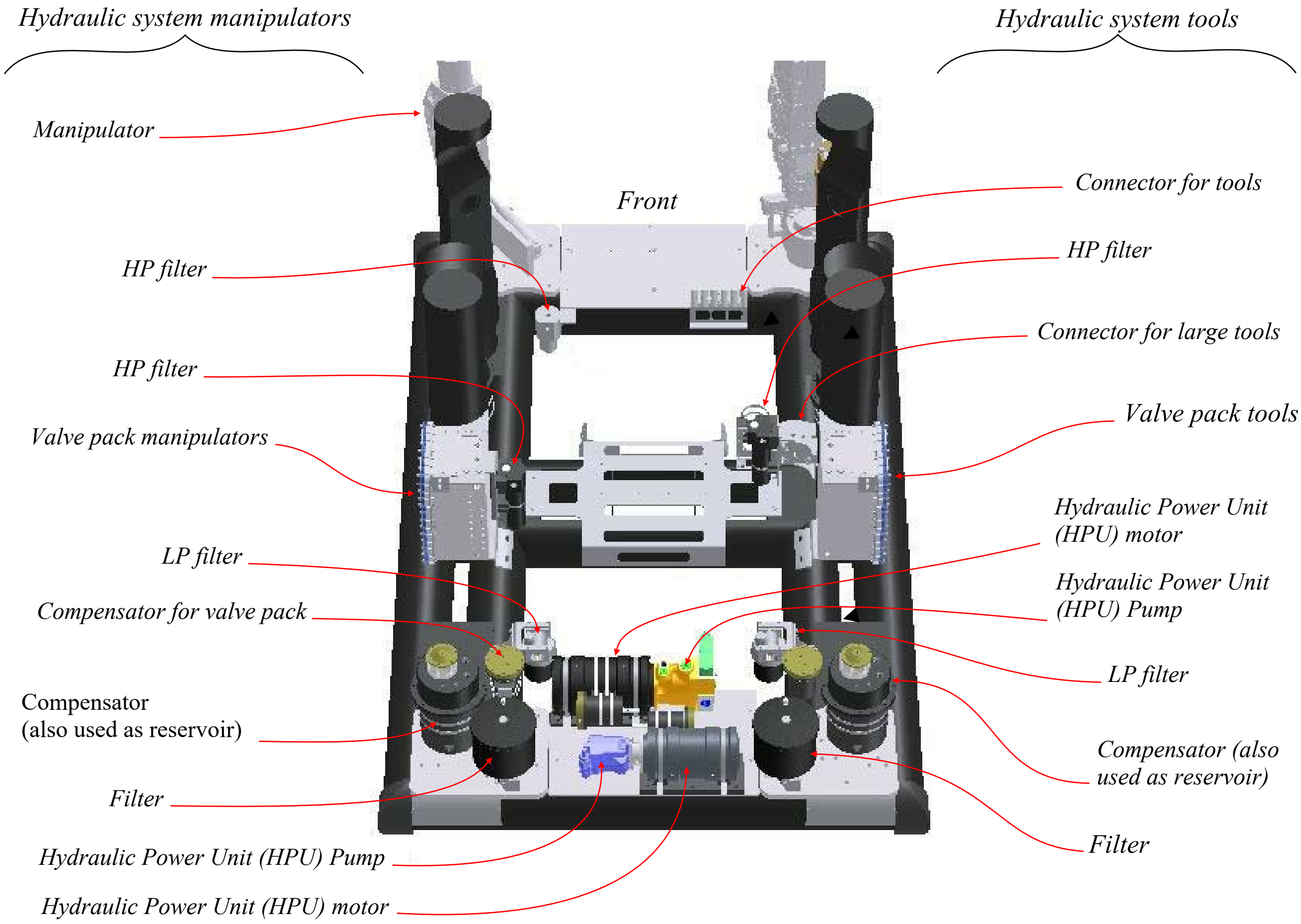
6.3.6.2 - Electrical & electronic components housing

Electric and electronic components are housed in waterproof containers, which are usually installed in protected areas. Some units are kept with an internal pressure below the atmospheric pressure (it is called "void") to ensure they are sealed, some others are oil-filled and pressure compensated to prevent water intrusion that can be detected visually or by sensors. Note that these pressure vessels are also called "electronic bottles" and protect components such as:

- Power distribution systems
- Sensing systems and their connectors
- Gyro compass *(see the description in* *point 8.2.4.3.2**)*
- Sonar system *(It consists of two transducers which transmit an acoustic signal and receives the echo)*
- Camera and lights connections
- Multiplexer *(It decodes the information received from the surface, and encodes those sent to it)*

6.3.6.3 - Hydraulic system

The Hydraulic Power Unit (HPU) provides power to the elements of the ROV that are hydraulically activated, such as tools (grinder, saw, cable cutter, and others), manipulators, and the thrusters with some machines. It is composed of a pump that is driven by an electric motor, a manifold incorporating servo valves controlling the hydraulic circuits and acts as compensator and reservoir, and filters that remove contaminants present in the circuit.
An example of hydraulic circuit is the WR 200 that is equipped with manipulators and tools that are hydraulically driven. This machine has two separate hydraulic systems: One for the manipulators, and one for tooling. Note that the thrusters of this model are electric instead of hydraulic. The models hydraulically propelled have an additional circuit that can be shared or separate.



6.3.6.4 - Manipulators

Manipulators are articulated arms that allow performing various tasks such as:

- Objects and debris recovery
- Equipment deployment and recovery
- Shackle releasing *(these shackles are specific for ROVs)*
- Installation and recovery of transponders

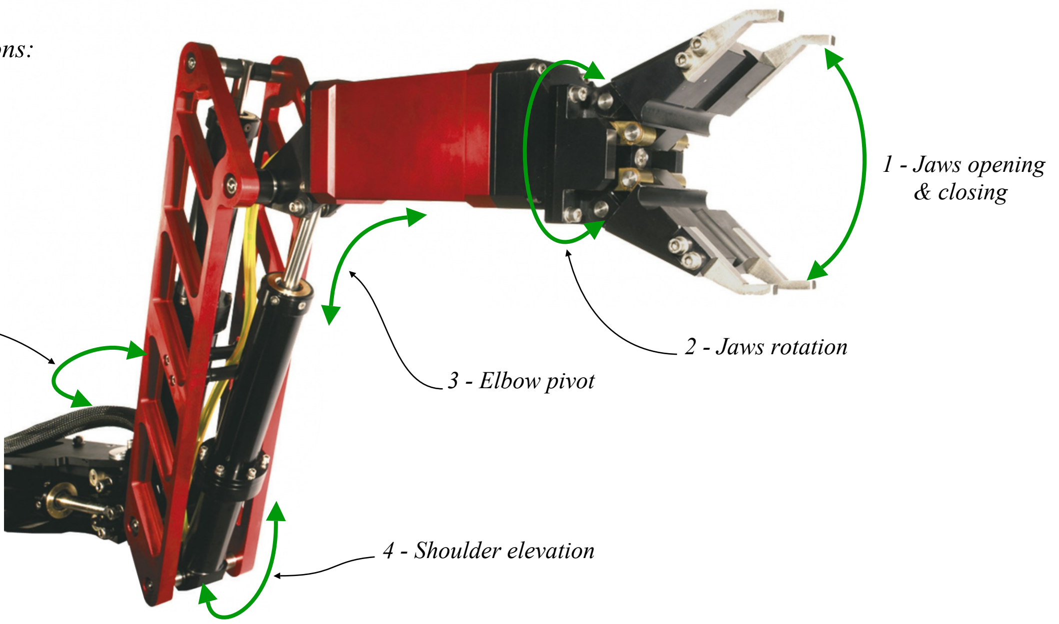
- ROV stabilization while working on a structure
- Handling inspection and cleaning tools
- Operating subsea valves *(through specific connectors designed for ROVs)*

Manipulators can be electrically or hydraulically powered:

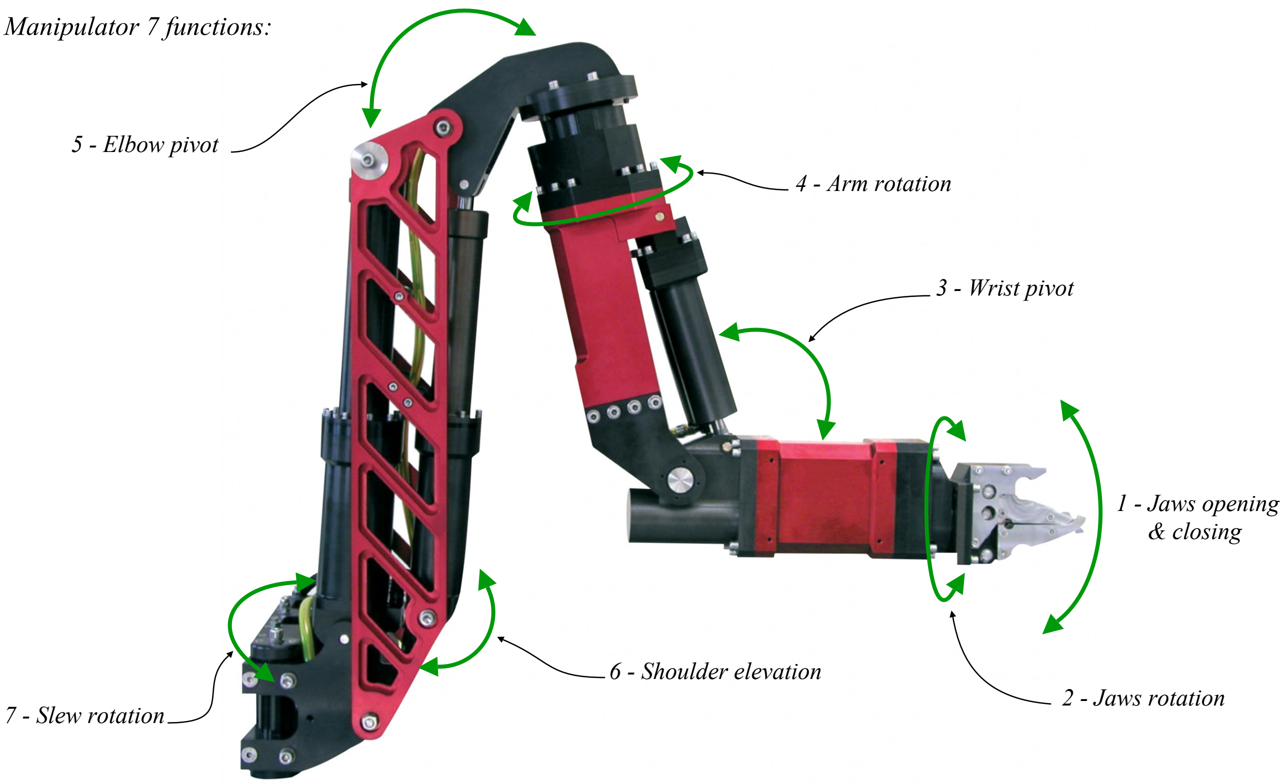
- Electrical units provide the advantage of avoiding the installation of hydraulic systems that are too heavy to be carried by small machines. They are motioned by several electric motors and gears. These systems are found on class 2 ROVs, and can also be found on some work class machines, but the current models are limited to 40 - 50 kg in lift capacity
- Some models of hydraulic manipulators can lift weights of 500 kg. For this reason, they are installed on a lot of work class ROVs designed for works requiring a lot of power. They are motioned by several hydraulic jacks powered by the ROV's HPU *(see point 10.3.5.3)*.

Manipulators are also classified by the number of "functions" they provide. Note that what is called a "function" corresponds to a move that can be performed.
As an example one "function" manipulators can only open or close jaws that are mounted at the end of a fixed arm. They are found on very small ROVs.
Manipulators installed on work class ROVs usually have, but not always, 5 and 7 functions. The two units below, that are designed by ECA - HYTEC, are examples of the moves they allow.

Manipulator 5 functions:



Manipulator 7 functions:



When selecting an ROV for the rescue of a bell, it is essential to check whether its manipulators are sufficiently powerful and articulated for this usage and whether their weights affect the machine.
As an example of a machine that is compatible, the WR 200 from IKM is equipped with one five functions manipulator ("Rig Master", fabricated by Schilling), and a 2nd unit that allows for seven functions ("Titan 4", also made by Schilling).

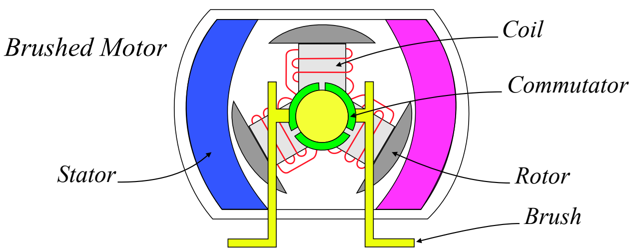
- The manipulator five functions can lift 270 kg maximum and 181 kg when fully extended, its weight is 64 kg in air and 48 kg in the water *(see #1 below)*.
- The seven function manipulator weights 100 kg in air, and 78 kg in the water. It can lift 454 kg and 122 kg when fully extended *(see #2 below)*.

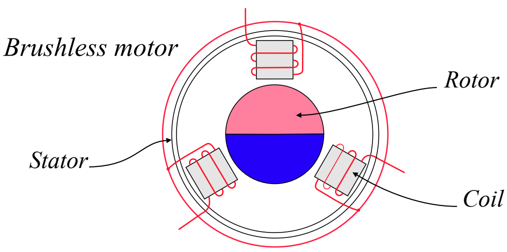
Note that whether the five functions manipulator (which can be four functions) is usually commanded by the pilot *(See point 10.3.3.1)*. The 2nd manipulator is generally operated by another technician (ROV Tooling). The joystick used for this purpose is articulated similarly as the manipulator. So the operator can perform with his hand the moves he wants the manipulator to do *(see #3 below)*.

6.3.6.5 - Thrusters

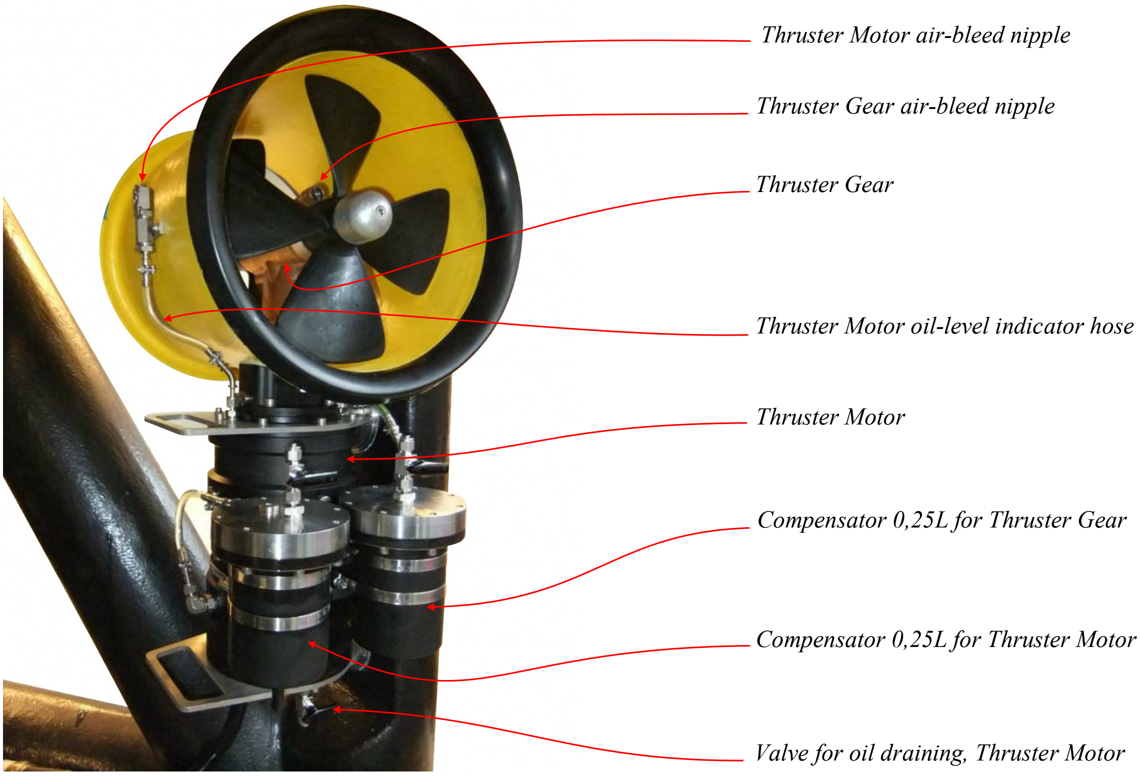
Thrusters are installed to provide the vehicle with horizontal, vertical, and lateral movement. They can be hydraulically powered or electric.

Observation ROVs are usually propelled by electric thrusters. The main reason is that electric thrusters have the advantage not to require a hydraulic system, which is an advantage with machines that are too small to carry this additional equipment without impacting their payload. However, some work class machines of the last generation are also equipped with electrical thrusters.
New models are activated by brushless electric motors powered with AC or DC, housed in pressure compensated vessels that are oil-filled, and usually fitted with gear assemblies. This design provides the advantage to allow the thruster running without damage to the winding or electronic components in the event of a shaft seal failure and subsequent flooding. Thus, it solves the main problem encountered with the previous generation of electric thrusters, which propeller shaft is directly connected to the motor, isolated by only one seal, and so more prone to water intrusions.
The difference between brushed and brushless motors is that with brushed motors the current passes through coils that are mounted on the rotor. This assembly rotates because each coil generates a magnetic field that is pushed away from the pole of the stator of the same polarity and is pulled toward the one of opposite polarity. The power to these coils is supplied through fixed conductive brushes that make contact with a rotating commutator.
With brushless motors, the coils are located on the stator instead of the rotor that is made of two separate polarities permanent magnets. As a result, the coils do not rotate and there is no need for brushes and a commutator.





As an example of last generation electric thrusters described in the previous page, the model below that is used on the Merlin WR 200, is powered by a motor in a oil compensated compartment. This model has the particularity that the motor is separated from the gear and not aligned with the shaft of the propeller. Note that the function of the air bleed nipples is to ensure that the containers are fully filled with oil.

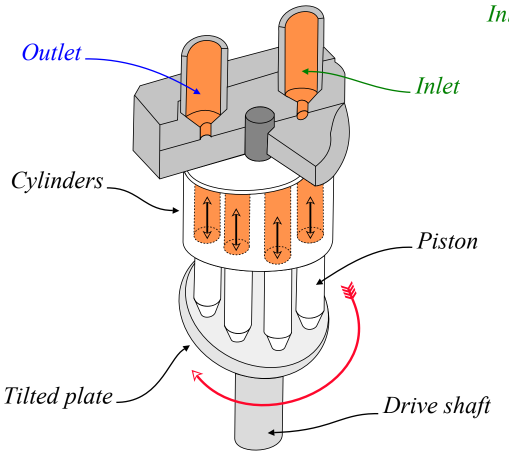


Hydraulically powered thrusters are driven by hydraulic motors that convert the fluid pressure from the HPU into a rotary motion. These motors may be combined with mechanical drives such as gears.

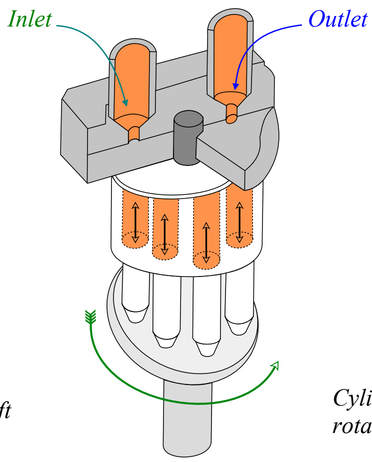
Variable displacement pumps are used in most hydraulic ROVs to save energy and reduce the heating of oil. Opposite to a fixed displacement pumps which amount of flow cannot be changed, and oblige the use of a flow control valve, a variable displacement pump can have its cycle altered so that the displacement will change proportionately to the change in the cycle speed or rate. A common variable displacement pump is the axial piston pump that is composed of several pistons that convert the rotary shaft motion into axial reciprocating motion. They are composed of a tilted plate that rotates, causing the pistons to move up and down, and thus, take the fluid and expel it each shaft rotation. Playing on the orientation of this plate modifies the flow of the pump.

Note that hydraulic motors have the reverse function of pumps, and for this reason, have similar designs. Thus, an axial piston motor is a pump working in the reverse cycle *(see below)*.

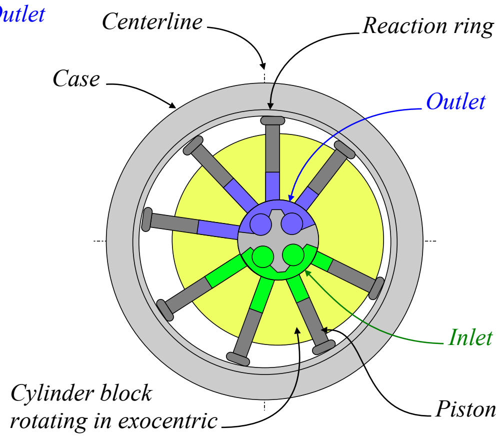
Radial-piston motors are also used. They are composed of a cylinder barrel that contains pistons that reciprocate in radial cylinders attached to the drive shaft. The outer ends of these pistons bear against a thrust ring. The hydraulic oil that is pressurized by the pump flows in the center of the cylinder barrel to drive the pistons outward. As a result, the pistons push against the thrust ring, and the reaction forces rotate the barrel.



Axial piston pump



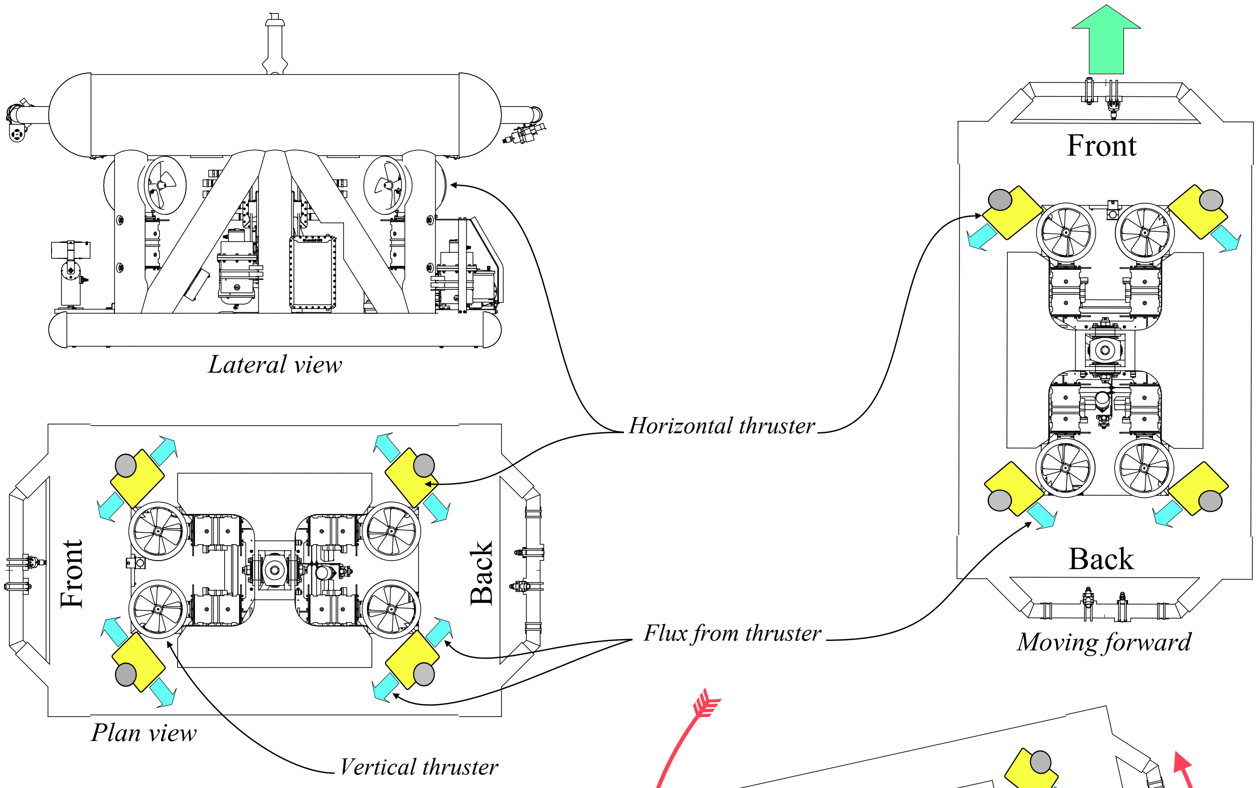
Axial Piston motor



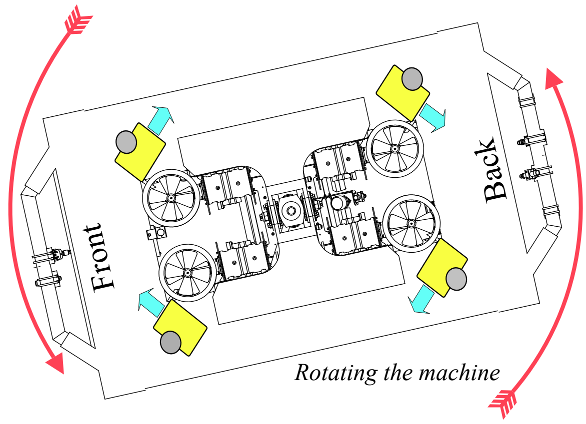
Radial piston motor

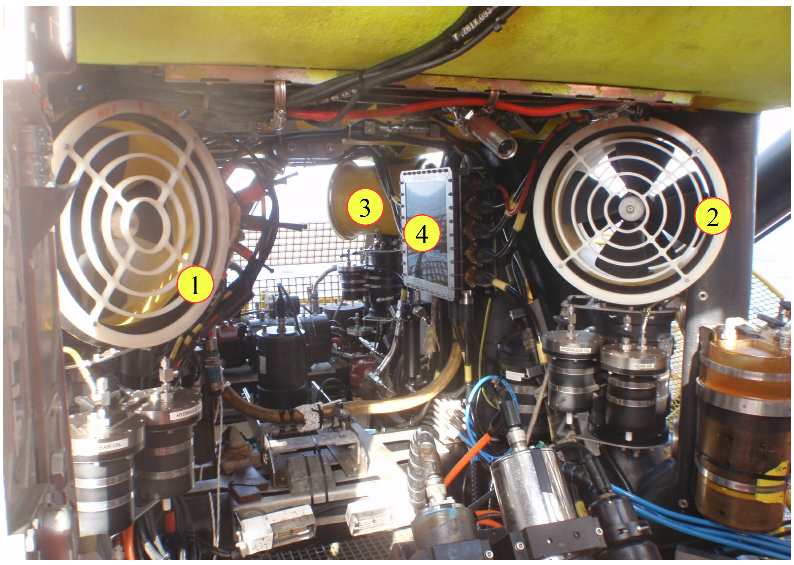
Servo valves or similar systems that are paired with the pumps and the motors allow controlling the propellers.
Hydraulic motors are reputed to provide high torques and have a better speed of response than electrical units. It is the main reason they are installed on Work Class machines.
However, some electric thrusters of the last generation, such as the one described above, are now capable of similar performances.

Thrusters are positioned to push the vehicle in any direction. As an example, the Merlin WR 200 has four horizontal thrusters and four vertical thrusters that can work in both directions (rotating & contra-rotating). Its horizontal thrusters are positioned at 45º to move it forward, sideward, or rotate it. This configuration, which is called "X-shaped ", is ideal but the fluxes are not in the axis of the ROV when it moves forward *(see the views below)*.

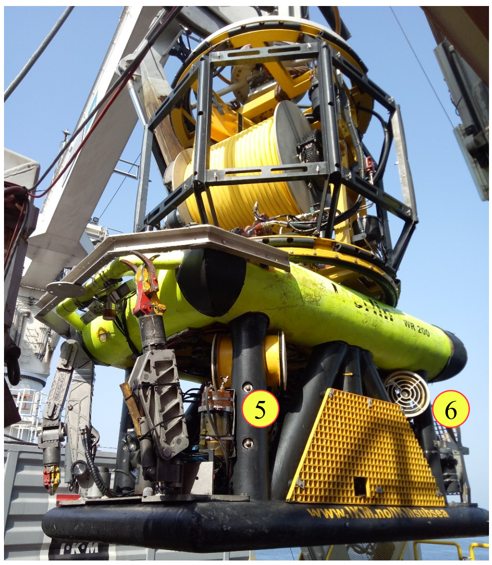


Note that the vertical thrusters of this machine are of the same model of the horizontal units and are organized to work all four simultaneously. This solution that is implemented on a lot of new models gives the advantage to limit the spare parts to be provisioned.
However, it happens that for technical reasons, some machines are equipped with only one or two thrusters of deferent models than the horizontal ones.





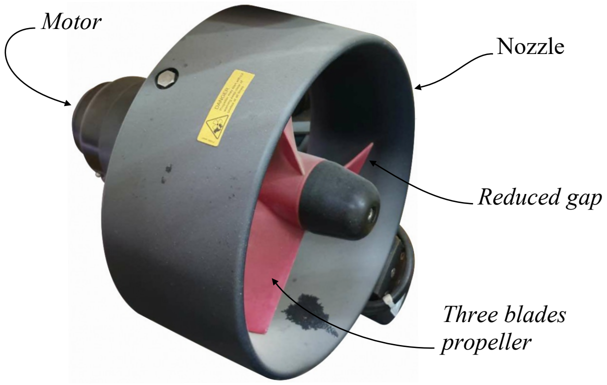
Forward thrusters: #1 & #2 - Stern thruster: #3
Oil filled pressure compensated electrical connection box #4



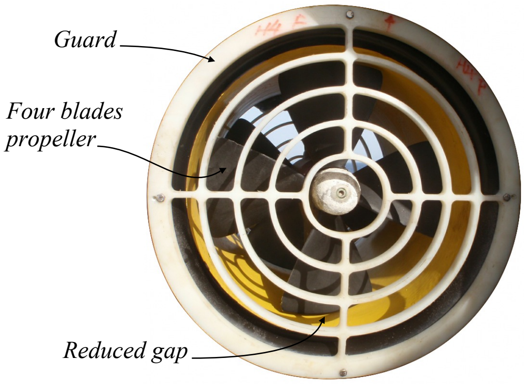
Forward thruster: #5 - Stern thruster: #6

The propellers of work class ROV thrusters are of fixed pitch types, with three or four blades that are installed in nozzles, like in the model on the next page, which is installed on a Seaeye Panther. As already discussed in point 8.2.3.1 of this book, the advantage of the nozzle is that it increases the velocity of the water flow, and so allows for a more efficient thrust than a standard propeller. Also, the very reduced gap with the extremities of the blades eliminates the vortices and the effects of cavitation.

Some propellers, such as those used on the Merlin WR 200 previously discussed are organized in tunnels. The advantage of this configuration is that it allows to house two thrusters, one to move to one way and the other to move to the opposite direction *(see in the right side below)*.
Note that when an ROV is to be used in the vicinity of divers, its thrusters must be fitted with guards to avoid the divers being injured by them. These guards must restrict any hand or finger intrusion *(see the photo on the left side below)*. The inconvenience of these protections is that they impact the flux from the thrusters, and so they lower their efficiency.



Electric thruster with a three blades propeller (Seaeye Panther)



Electric thruster with a four blades propeller (Merlin WR 200 IKM)

The manufacturers express the forward, lateral, and vertical thrusting capabilities of their machines in kilogram-force (kgf) or kilo Newton (kN) (1 kgf = 9.8 Newton). Note that whether the force of the horizontal thrusters in important to move the vehicle in harsh conditions, the force of the vertical thrusters of an ROV is crucial because it provides the ability to operate similarly as a helicopter, and thus lift loads without being obliged to connect the crane or similar devices. The vertical thrusting capabilities of an ROV must not be confused with the payload that can be adjusted by playing on the buoyancy of the machine. Depending on the machine, class 3 ROVs have a forward thrust between 300 to 1100 kgf, a lateral thrust between 290 & 1100 kgf, and a vertical thrust between 200 & 1000 kgf.

6.3.6.6 - Camera and Lights

Cameras are used for numerous tasks such as driving the ROV to and from the target, give an overview of the work site, control the manipulators, provide a detailed view of an object, check the connection to the TMS, verify the condition of the umbilical reel in the TMS. Additional cameras maybe fitted for specific tasks along with still cameras for inspection projects.
These Cameras are paired with powerful lights that can be dimmed and are usually mounted on a pan and tilt assembly. Some last generation cameras have Light Emitting Diodes (LED) around their lens, which provide lighting aligned with the lens of the camera and save the weight of a separate light.

Note that additional cameras are sometimes installed to give views of objects from different angles than the primary camera. The combination of an angled picture with the front one may allow seeing whether the tool is adequately positioned for the task planned. Also, that allows the pilot and the tool operator to cope with the deformation of the picture resulting from the refraction of the water. However, some cameras are now equipped with “dome viewports” that fix this problem and allow for a field of view of 90° instead of 64° with a flat viewport. The spherical curvature of dome viewports allows rays to pass through the surfaces without deflection on their way to the lens. Also, a dome-shaped viewport is better able to withstand extreme pressures than a flat one.

Manufacturers express the performances of cameras as follows:

- Minimum light sensitivity is expressed in “lux”(lx), which is the International System (SI) unit of luminance (light). One “lux” is equal to one lumen per square meter.
  The “lumen” (lm) is the unit used for the total luminous flux in a light beam. For convenience, it is common to compare the lumens emitted by a light beam with the power of light bulbs, so 150 lumens can be roughly correlated with the light emitted by a 10-watt bulb, and 1500 lumens corresponds to the light emitted by a 100-watt bulb. Thus, a 100-watt bulb that fully illuminates a surface of 1 m^2 is equal to 1500 lux, and 1 lux is equal to the luminescence of a bulb of 0.0666 watts.
  Another simple and practical method to compare the luminance is to keep in mind the following values:
    - Overcast night = 0.0001 lux
    - Star light night = 0.001 to 0.002 lux
    - Quarter moon with clear sky night = 0.01 lux
    - Full moon night with clear sky = 0.1 to 0.4 lux
    - Sunrise or sunset on a clear day = 400 lux
    - Overcast day = 1,000 to 2,000 lux
    - Daylight 10,000 lux
    - Sunlight= 110,000 lux.

  The lower the lux rating the more the camera is able to see in low light conditions.
- The resolution of analog cameras and screens is given in “horizontal lines”:
  The resolution of analog cameras and monitors is calculated in Television Lines (TVL).

- "Horizontal Resolution" is the number of alternating vertical black and white lines from the left to the right of the screen.
- "Vertical Resolution" is the number of the alternating horizontal black and white lines from the top to the bottom of the screen.

It is common to use the measure of the horizontal lines to indicate the resolution of a camera or a screen. Note that the highest resolutions are those that have the highest number of lines.

- Digital screen specifications of TV and computers are given in "horizontal" and "vertical resolutions". The "horizontal resolution" corresponds to the number of elements, dots or columns from left to right on a display screen, and the "Vertical resolution" is the number of rows, dots or lines from top to bottom.
  As examples of resolutions that are found with computers and video combos note 1280 x 720 and 1920 x 1080 that are also called 720p & 1080i ("p" means refers to progressive scan, and "i" means "interlaced").
- The resolution of digital cameras and screens is often indicated in megapixels.
  A pixel is a tiny colour square that is assembled to others to create a digital image. So, the more pixels used to represent an image, the more accurate the picture is. Pixels can be plus or less numerous in a picture and used as a unit of measure, such as an example 2400 pixels per inch.
  Megapixel means one million pixels. Thus, a 12-megapixel camera can produce images with 12 million pixels. The formula to calculate the resolution of a digital picture is "Number of horizontal pixels × Number of vertical pixels". As an example, a camera with 4928 by 3264 pixels has a resolution of 16 megapixels.
- Some cameras are also provided with zooms, which are devices that are used to make a subject appear closer. Two systems can be used:
  - Optical zooms consist of a series of lens and glass elements that are adjusted in or out through a system of screws and miniaturized gears. They are reputed to give the best results of image magnification. Their main problem is that the waterproof housing of the camera may limit their ability to move, so they are limited in performances compared to units not designed to go underwater.
  - Digital zooms achieve a similar effect to optical zooms, without mechanical work of lenses and glass elements. These systems cut off areas around the target, which is enlarged using algorithms that add pixels to preserve the detail of the magnified image. However, specialists say that this process is imperfect and that some digitally zoomed images may be blurry and smudgy.

  The zoom capability of a lens is usually expressed as the ratio between its longest and shortest focal lengths. For example, a zoom lens with focal lengths ranging from 50 mm to 200 mm is referred to as a x4 zoom lens.

Cameras and display combos of ROVs are essential as they are the eyes through which the pilots and the persons observing the scene for inspection or diving monitoring purposes can see. Clients and organizations usually request a low light navigation camera and a colour or a high definition camera as a minimum. Nevertheless, manufacturers of class 3 ROVs equip them with more units than this minimum and provide connectors to add additional units, as indicated previously. As an example, in addition to low light and colour cameras, the Merlin WR 200 is initially equipped with two other colour cameras on the front, plus one unit on the rear and another one for the TMS docking.

- Low light cameras are sensitive enough to show detailed pictures in a dark environment where most cameras show only black. The pictures of these analogic cameras are usually in black and white. However, some new digital models that provide images in colour are proposed.
  Such cameras are mostly used for navigation. However, they can also replace colour cameras when the water turbidity does not allow for the use of lighting without being dazzled by its reflection on particles.
- Colour analog cameras are used for all kinds of works, including inspection, and are often fitted with a zoom. These cameras are also used to navigate when the water turbidity allows. These models have not evolved so much these last ten years; the main improvements are their housings, which some of them allow dives up to 6000 m.
- High definition digital cameras, which some are equipped with zoom, can be used for the same operations as analog models, and tend to replace them. The manufacturers continuously improve their performances that have been multiplied by 10 since the first models. Besides, these cameras are designed to store photos and films at the quality they have been taken, which allows them back up (this point is mandatory with Norsok U102).

The quality of the image displayed is essential, and for this reason, clients and organizations also require minimum performances. The requirements of NORSOK U102/2016 are indicated below. However, they are based on more than ten year old references and may change in the next revision. For this reason, it is better to refer to last-generation devices and select the highest performing equipment not to be affected too fast by the obsolescence of standards.

	Low light camera		*Colour camera*		*High Definition camera*	
	Norsok	*Last generation*	*Norsok*	*Last generation*	*Norsok*	*Last generation*
Sensitivity	0.03 lux	0.000,05 lux	1 lux	0.9 lux	0.1 lux	0.1 lux
Resolution	> 400 TVL	570 TVL	> 400 TVL	550 TVL	2,1 megapixels	>20 megapixels
Field of view	60°	77°	–	90°	–	90°
Depth of focus	150 mm to inf.	150 mm to inf.	–	–	–	–
Zoom	–	–	–	x 36	–	x 30

Lights are the complement of cameras and should be powerful enough to illuminate the worksite perfectly during optimal conditions. Due to the absorption of the light by the water, the more powerful the lighting, the better it is. However, the number of floodlights that can be installed is often limited by the number of fixation points available on the machine and the electrical power that can be supplied.
Most lights that are manufactured for ROVs are today made of Light Emitting Diodes (LED), and use 24 to 48 volts DC or 110 - 120 volts AC. These lights are more efficient than traditional bulbs.
As a reference of lighting provided on class 3 ROVs, the Merlin WR 200 can be equipped with four lights 7500 lumens each and a spotlight 4366 lumens mounted on its front, Plus one spotlight 4366 lumens at the rear and another one of the same power for the TMS docking. Thus, the machine can provide a maximum of 34366 lumens at its front, which is the approximate equivalent of the light emitted by 229 bulbs of 100 watt each.
Lights may not be usable at their full power for the reasons linked to water turbidity already described. For this reason, manufacturers provide a system that allows dimming them.

Note that whether some cameras and lights are mounted on fixed points, some others are installed on “pan and tilt units”. These devices enable the pilot to remotely drive the cameras into position to give the best views while moving or holding the vehicle stable. There are several different types available, from cylinder driven rack and pinion units to rotary vaned and multi-thread piston actuated units. At a minimum, they should allow moving 90º vertically and 120º horizontally.

1 - floodlight

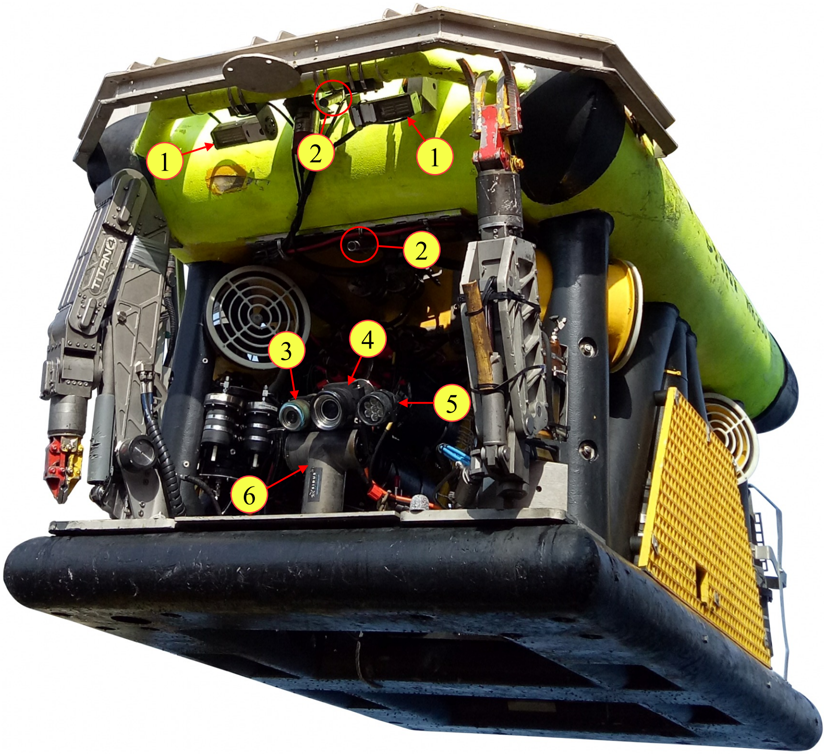
2 - HD camera

3 - Low light camera

4 - Colour camera

5 - Spotlight

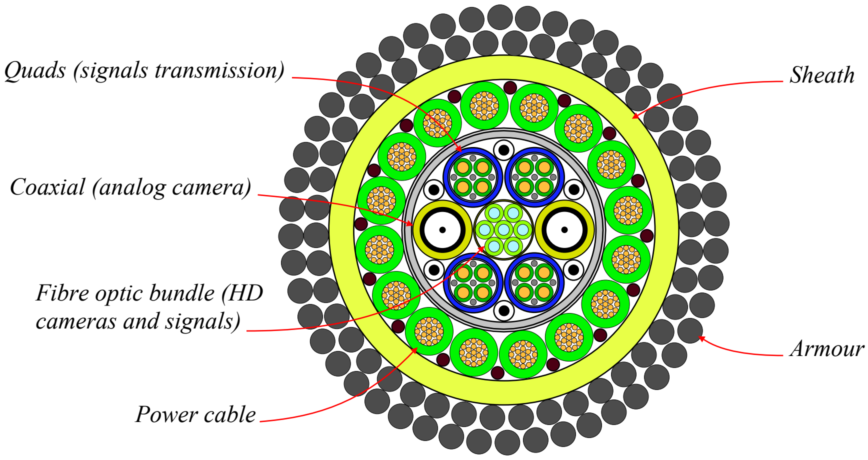
6 - Pan & tilt unit



6.3.6.7 - Umbilical

As previously said, a typical ROV umbilical carries the control signals from the control console, information from the vehicle sensors, and the electrical power required to operate the ROV.
Depending on the system used it may be only one length terminated at the winch junction box on the Launch and Recovery system (LARS), previously described in point 10.3.4.1, or be composed of an armoured length that is reeled in the surface winch of the LARS and hold the Tether Management System , and of a 2nd umbilical which is reeled on the winch of the TMS and which the other end s connected to the ROV. In the case that the ROV umbilical is terminated in the TMS, Intermediate junction boxes similar to those described in point 10.3.4.1 are mounted on the winch of the TMS.
The umbilical is organised as below:

The umbilical is organized to protect the most fragile components:
1 - The fibre optic bundle is in the center
2 - The communication cables are around the fibre optic bundle.
3 - The power cables are organized at the periphery of the umbilical, so they rigidify it.
The external sheath provides insulation and protection. It is the latest layer of standard umbilicals not designed to lift the ROV.
The armour is part of umbilicals with lifting capabilities. Thus, the umbilical from the surface to the TMS.



Note that umbilicals must be secured such that the connections in the junction boxes are not under stress. For this reason, they are secured to the frame of the machine through a “Chinese finger” that is usually inspected every day. The umbilicals are also secured to the reels of the winches. Also, it is recommended to always let a minimum of 5 turns on these reels.

6.3.7 - Navigation and technical aid systems

These functions are usually indicated in the description of the machines provided by the manufacturers and the operators. Note that some terminologies

6.3.7.1 - Navigation aids

- Gyroscope & gyro compass:
  A Gyroscope detects and measures the angular motion of an object relative to an inertial reference and has the orientation of its axis unaffected by tilting or rotation. So, it measures the absolute motion of an object without any external infrastructure or reference signal. These devices that were initially mechanical systems mounted on a gimbaled support are today replaced by electronic sensors. A gyrocompass is a navigational device that is built around a gyroscope movement. They are used for functions such as auto heading and must have a resolution better than 1°.
- Auto heading:
  This function allows entering a pre-determined heading to which the machine always moves to as long as the pilot does not deactivate it. As said above, it uses the gyroscope that is monitored continuously and acts in such a way as the thrusters are automatically directed to maintain the vehicle in a fixed direction.
- Auto depth:
  Depth is the distance of the ROV from the surface. This function works on a voltage that is derived from a pressure sensor is compared to a reference signal. The resulting signal is applied to the vertical thrusters which act in such a way as to counteract the change in depth. Note that depth sensors should have a precision of at least 0.1 m.
- Auto altitude:
  Altitude is the distance of the ROV from the seabed. The system utilises the gyro to detect any change of altitude and make an adequate correction using the vertical thrusters. The altimeter should have an accuracy of 0.1 m.
- Inclinometers:
  It often happens that the ROV rolls and pitches during the operations, which may result in a disorientation of the pilot. For this reason, instruments are mounted to show the angular movements of the vehicle, that are often graphically displayed on the screen with the degrees of roll or pitch and an artificial horizon. Their accuracy should be better than 1°. Note that some machines are equipped with automatic correction systems.
- Navigation SONAR
  SONAR stands for “Sound Navigation Ranging”. The sonar assembly consists of a transducer that transmits an acoustic signal and another one that receives the echo. This device that operates horizontally, and may be mounted on a hydraulically operated tilt mechanism, is used to look for obstacles that are not visible through cameras. The display of the sonar is usually on an adjacent screen. Clients often require a range from 1 to 150 metres.
- Imaging SONAR
  It is a particular type of SONAR enabling a photographic type view of the sea bed, that allows the positioning of topographical features, structures, and debris on the worksite in the absence of visibility and from long distances. These sonar can also be used to take pictures of items such as flanges in waters of high turbidity.
- Doppler Velocity Logs (DVL):
  A “Doppler Velocity Logs” is a sonar system that emits sound bursts angled downward in various directions, that are returned to the receptors of the emitting vehicle. These returned echoes carry a change in pitch called “Doppler effect”. Combining these readings tells how fast the ROV is moving and in which direction.
- Trim controls:
  The function of the "trim control" is to free the pilot from permanent corrections with the joystick in case of established currents that push the ROV, or in the case of a modification of the buoyancy. So, this function allows the pilot to focus on his task as the ROV is making the asked corrections.
  Depending on the machine, the trim function is activated through a switch, a potentiometer, or a button on the touch screen near the pilot. When enabled, the system maintains a control signal to the vehicle that automatically applies corrections according to the control selected.
  Among the functions available, forward/reverse, vertical up/down, and lateral port/starboard are the most common.
- DP systems
  DP systems for ROVs are new applications that can be optional with some last-generation machines and are still experimental and under evaluation by a lot of manufacturers and competent organizations. The purpose of these systems is to provide significant levels of automatic control functions such as absolute DP (ROV dynamic positioning regardless of ship motion) or relative DP (ROV dynamic positioning relative to ship motion).
  ROV dynamic positioning applications can be achieved with Gyro based Inertial Navigation Systems (INS), depth sensors, Doppler Velocity Logs (DVL), and acoustic positioning systems such as Ultra Short Baseline System (USBL) and Long Baseline System (LBL).

6.3.7.2 - Technical aids

- Main display:
  This display provides the picture from the video camera in use. Also, it provides essential information such as the ROV heading, depth and altitude, pitch and roll, oil pressure, temperature, and others. However, note that several displays are used for this function with class 3 ROVs *(see in point 10.3.3.1)*.
- Multiplexer data:
  This function allows visualizing whether data are transmitted through the multiplexer.
- Water intrusion and current leakage sensors:
  Sensors are provided to inform of water intrusion or condensation in the system, and some others of current leakage.
- Power used by thrusters:
  The power that is used by the thrusters is displayed graphically and in percentages on the main display or an additional screen *(see in point 10.3.3.1)*. That allows adjusting their output or the piloting to preserve them.
- TMS bail count:
  It is a system that allows the pilot to know how much length of umbilical is off the TMS. This distance is displayed on the main or an adjacent screen.
- Vehicle turns count
  It often happens that during some operations, the pilot pivots the ROV several times around its axis in one direction without realizing it. That may exaggeratedly twist the umbilical and damage it. The vehicle turns count system allows the pilot to visualize how many turns the ROV made on itself to one direction and thus return it to zero to preserve the umbilical. This function is usually displayed on the main panel.
- Self diagnostics program:
  The "Self diagnostics program" continuously monitors the circuit boards of the system. Should a fault occur, then a surface computer allows the operator to step through the system and locate the affected circuit board.

6.3.8 - Emergency locating and recovery equipment

ROVs carry battery-operated transponders, which aid in the locating and recovery of the vehicle should the umbilical break. Also, they are used for navigation purpose and allow to locate the ROV permanently through the survey system of the vessel. For these reasons, these systems are the most employed and the most required by clients.
ROV teams usually install a transponder on the ROV and another one on the TMS system, to precisely locate them on the nav screen. note that the batteries of these systems should allow for several days of autonomy.
Also, it must be taken into account that work class ROVs operating at the proximity of divers should be equipped with such a system, so the diving supervisor can see where it is on the nav screen.
Note that some units are equipped with a "responder", which is a system similar to the transponder, except that the "interrogation" signal that triggers the answer by an acoustic pulse through the water is sent through the umbilical.
Some models of ROVs are equipped with a pinger in addition to transponder or responder. Pingers, that are mandatory on diving bells, are devices that repeatedly emits short pulses of acoustic emissions at a set frequency. They allow locating a lost ROV by triangulation of the emission.
Also, the ROV should be equipped with a flashlight that is powered by independent batteries. This device usually starts when it reaches the water and automatically stops when the machine is back the deck. The flashlight is essential for visually locating the ROV.

In addition to the locating equipment, an appropriate rigging should be ready for the recovery of the machine by the crane. It is prudent to plan for slings and shackles that are designed with a safe working load allowing lifting double the weight of the ROV in the air in the case of a complicated recovery. Soft slings are the preferred option.

6.3.9 - Tools used for various manipulation and cutting tasks and also diving bell recovery

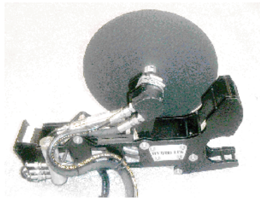
A class 3 ROV must be equipped with minimum tools to perform various manipulation and cutting tasks and also rescue wet or closed diving bells.

- Four, five, and seven functions manipulators:
  Manipulators are explained previously. Four and five functions manipulators are generally used to grab objects and/or maintain the ROV in position. The seven positions manipulators are designed to perform all the movements which could be possible by a human arm and perform more delicate tasks.

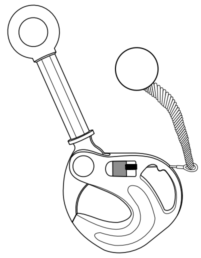
- Water jets and brushes:
  These tools are used to perform cleaning operations. HP water jets and cavitation jets (see #1) are usually energised by a pump that is part of the ROV. It is also the case of rotative brushes (see #2) that can be motioned hydraulically or electrically.

- Cable & umbilical cutters:
  These tools use the principle of the guillotine and are typically installed at the end of one arm. The unit selected must be capable of cutting the main and the guide wires of the bell. Also, note that some models are designed to cut umbilicals up to 270 mm diameter.

- Grinder:
  This tool can be used to cut metal and concrete and the umbilical of the bell if necessary. Diamond disks with diameters sufficient to cut the objects in one pass are recommended.



- Hook:
  Only hooks specifically designed for handling by an ROV should be provided in case of lifting operations. Also, they must be included in the tool kit to rescue a diving bell. They can be grabbed and orientated using the five positions manipulator of the ROV and opened or closed using the seven-position manipulator. The locking mechanism is often integrated with the body of the hook, and a ball connected to the latching system by a small cable allows the ROV to trigger its opening.



6.3.10 - Video display & recording, and communications & alarms

6.3.10.1 - Video display & recording

The video signals from the cameras are sent to the control room through the multiplexer. Then the signals are converted to the format of the displays and the recorders.
In addition to the displays in the ROV control room, the video signal of the camera in use is transmitted to the screens of the diving supervisor, the bridge, the Offshore Construction Manager (OCM), and the clients.
The pictures displayed should indicate essential information such as the date and time, the name of the pilot, the project and location, the task performed, the heading, the depth, the altitude, the roll & pitch. Some clients may require more elements.
Note that video displays from the divers should be in place in the ROV room. So the pilot can have a picture of what the divers see.

Video recorders are the complement tools of cameras. Safety organizations and clients ask that two units are provided in the ROV control. Also, the recording of dives should be kept at least 24 hours. Regarding this point, the new systems allow storing them for a longer time, and most teams transfer them to external media where they are saved forever when the project is completed.
The last generations of video recorders are digital systems installed in dedicated racks. They are provided with functions that allow adding overlays and annotation in addition to logos and information about the job. Screen splitters are also provided to allow viewing several cameras on the same screen.
New systems also provide tools to isolate photos or part of a video recording as well as anomaly clips with their logs. The full logs can also be introduced in the records. The files are typically edited in formats that are common to every computer and digital video reader.
These systems are provided with hard disks where the video files are saved, and that can be accessed through a data bank. Also, USB (Universal Serial Bus) connectors are provided to transfer these files to external drives or download those kept in the cameras.
Note that clients commonly request recorders with the functions described above.

Also, because new video recorders are in fact computers, some software developers propose to adapt classical laptops and desktops to this function.

6.3.10.2 - Communications and alarms other than video

Wired communications must be in place with the Launch And Recovery System (LARS) for the launching and the recovery of the ROV, check the machine (Function tests), and ensure that the machine is cold when performing maintenance tasks.
Diving support is a particular ROV task that requires that the ROV pilot works in symbiosis with the diving supervisor and the bridge. For this reason, he must be in permanent communication with both, and the primary link used for this purpose must be hard-wired, immediately available, and unable to be interrupted. If the dive is organized from a facility, the Offshore Installation Manager (OIM) room must be connected through this channel
Note that this link must be organized such that it cannot be interfered with by other communications.
Backup systems must be in place in the case of failure of the primary system. They can be a second intercom system, the phone, and radio communications if relevant.

Key people such as the Offshore Construction Manager and the clients must have the possibility to contact the ROV control room and be reachable if needed. It is usually done through a dedicated intercom. Communications with some parts of the vessel such as the conference room should be possible.

In the case that loads have to be transferred, there must be direct communications with the crane operator. They must be of the same type than those used with the diving supervisor, bridges, and OIM room.

There must be a direct communication with the survey team, and a display that indicate the position of the ROV and the divers on the worksite must be in the ROV control.

DP alarms must be in place when the ROV operates from a DP vessel. The system and procedures is the one described in section 4.2.7.2.

Vessel alarms must also be installed in the ROV control. There must be the possibility to mute them

6.3.10.3 - Summary of communication and alarms required by clients and various organizations

Competent bodies emit guidelines regarding communication systems that are the minimum to be in place. However, numerous clients have more stringent requirements that cannot be ignored. The table below summarizes the requirements from IMCA and other organizations and clients, and gives additional recommendations.

No	*Description*	*Requirements IMCA*	*Requirements from clients and other organizations*	*Additional information*
1	Hard wired communications to and from the bridge *(dedicated intercom)*	Mandatory	Mandatory	The primary link must be hard wired, immediately available, and unable to be interrupted.
2	Wired secondary communications to and from the bridge	Optional	Optional	The secondary link can be hard wired, or a dedicated radio channel.
3	Hard wired communications to and from the OIM room *(Operations from a facility only)*	Mandatory	Mandatory	It is only when the operation is organized from a facility. The primary link must be hard wired, immediately available, and unable to be interrupted.
4	Wired secondary communications to and from the OIM room. *(Operations from a facility only)*	Optional	Optional	It is only when the operation is organized from a facility. The secondary link can be hard wired, or a dedicated radio channel.
5	Hard wired communications to and from the launch and recovery console *(dedicated intercom)*	Not clearly indicated	Mandatory	These communications can be verbal if the console is in the same room as the supervisor.
6	Hard wired communications to and from the crane *(dedicated intercom)*	Nothing indicated	Mandatory	Radio is no more accepted as main communication with the crane
7	Hard wired communications to and from the saturation diving control room *(dedicated intercom)*	Mandatory	Mandatory	The primary link must be hard wired, immediately available, and unable to be interrupted. Verbal communications are accepted if the ROV pilot is in the same room as the diving supervisor (It is unusual with class 3 ROVs)
8	Hard wired communications to and from the surface orientated diving control room .	Mandatory	Mandatory with most clients and contractors	Surface orientated divers may be involved to rescue the bell. Hard wired communications have the advantage to be dedicated and not interrupted.
9	Hard wired communications to and from the survey control room (Intercom)	Nothing indicated	Mandatory with most clients and contractors	See above
10	Hard wired communications *(Intercom)* to and from Offshore Construction Manager (OCM) office	Nothing indicated (It can be the phone)	Mandatory with most clients and contractors	See above
11	Hard wired communications *(Intercom)* to and from the conference room	Optional (It can be the phone)	Optional (It can be the phone)	Onboard new vessels, this office is generally connected to the ROV control by hard wired communications
12	Hard wired communications *(Intercom)* to and from the inspection office	Optional (It can be the phone)	Optional (It can be the phone)	See above

No	Description	Requirements IMCA	Requirements from clients and other organizations	Additional information
13	Radio communications to boats cruising within the vicinity of the vessel	Nothing indicated	Optional	This system is optional, but required by a lot of clients and contractors.
14	Radio communications to key people or used as 2nd means of communication	Nothing indicated	Mandatory	The radio can be used as a 2nd means of communication with areas that have primary hard-wired communications
15	Phone (wired) communications to the areas indicated before and other parts of the vessel	Nothing indicated	Mandatory with most clients	Onboard new vessels, office and cabins are generally connected to the ROV control by phone communications
16	Video signal from the launching and recovery areas and appropriate working areas	Nothing indicated	Mandatory	ROV controls are usually in the dark when operating the machine, so the pilot needs a camera to see what happens on deck.
17	Video signal from the saturation dive control	Mandatory	Mandatory	The picture shows the display from the helmet cameras of diver #1 & #2.
18	Video signal from the surface orientated dive control	Not indicated	Mandatory with most clients	Surface orientated divers may be involved to rescue the bell. For this reason, the ROV pilot must have a visual of what is carried on
19	Data from survey control to combo screen.	Not clearly indicated	Mandatory with most clients	A data screen indicating the position of the vessel, the divers, the ROV and its TMS is common today and usually mandatory.
20	Video signals to the saturation diving control room	Mandatory	Mandatory	A video screen that displays the ROV camera to the saturation diving control room is mandatory.
21	Video signals to the surface orientated diving control room	Mandatory	Mandatory	A video screen that displays the ROV camera to the surface orientated diving control room is mandatory.
22	Video signals to the bridge & DP console (if relevant)	Mandatory	Mandatory	A video screen that displays the ROV camera to the bridge and the DP console is mandatory.
23	Video signals to OIM control room (Operation from a facility only)	Mandatory	Mandatory with most clients	A video screen that displays the ROV camera to the OIM control room should be mandatory when the operations are organized from a facility.
24	Video signals to the Offshore Construction Manager	Not indicated	Mandatory with most contractors	A video screen that displays the ROV camera to the OCM is mandatory with most contractors.
25	Video signals to client office	Not indicated	Mandatory with most clients	A video screen that displays the ROV camera to the client office is mandatory with most clients.
26	DP alarms	Mandatory	Mandatory	The ROV pilot must be able to mute the alarm to maintain clear communications.
27	Vessel emergency alarms	Not indicated	Mandatory	Fire alarm, abandon ship, personnel falling to the sea, gas release, etc. This alarm can also be muted.

6.3.11 - Maintenance

6.3.11.1 - Planned maintenance system

ROVs are complex machines, and each model has some design weaknesses that may affect its reliability during the operations. To avoid having the ROV in breakdown and all operations halted, the ROV team must perform the maintenance operations indicated by the manufacturer, and inspect the system regularly. Also, the operations of maintenance should be logged in the planned maintenance system that should be used to identify additional weaknesses not seen by the manufacturer and implement corrective measures.

The Planned Maintenance System (PMS) allows ROV operators to carry out the maintenance of their systems at scheduled intervals according to the requirements of manufacturers, classification societies, IMCA, and other diving or

safety organizations. Also, note that this equipment management system is mandatory by most of the organizations indicated above, the clients, and also in International Maritime Organization (IMO) that says in the International Safety Management Code (ISM):
The Company should establish procedures to ensure that the ship is maintained in conformity with the provisions of the relevant rules and regulations and with any additional requirements which may be established by the Company. In meeting these requirements the company should ensure that:
I. inspections are held at appropriate intervals,
II. any non-conformity is reported with its possible cause, if known,
III. appropriate corrective action is taken, and
IV. records of these activities are maintained.

Because ROV systems used offshore are onboard vessels, we can say that the implementation of the planned maintenance system of ROVs is mandatory for all companies working at sea.

The implementation of this system with ROVs is similar to the one used with the diving systems that is explained point 3.4 of the document "Description of a saturation system".

6.3.11.2 - Workshop

A workshop which is provided with the necessary set of tools to perform the maintenance of the ROV system is mandatory.
This workshop should provide a dry zone where the technicians can intervene on electrical components. Its illuminations should be between 1500 and 2000 lux, and the electrical installation (usually 220 volts) should be provided with a personnel ground fault protection. Also, fire protection must be provided in the form of extinguishers, water deluge system, smoke and flame detectors.
In the case that the ROV is planned to work in areas where harmful and flammable gas releases are likely and within the 500 m limit of all offshore installations of some countries, this workshop must be provided with a protection against harmful and explosive gasses *(see point 10.3.3.2)*.
Depending on whether the ROV is built-in or a transportable system, the workshop is in a room near the hangar in which the ROV is stored, or in a specific container installed at the proximity of the ROV. In the case that the workshop is in a container, the interventions on the machine are performed in the open air.
Note that interventions on the ROV may oblige to move the vessel outside the 500 m limit of facilities likely to emit hazardous gasses.

6.3.11.3 - Consumable and spare parts store

Consumables such as oil, tape, degreaser, and others should be provided in sufficient quantity to complete the project and face unplanned breakdowns.
Their storage should conform with the rules regarding the Control of Substances Hazardous to Health (COSHH), and similar fire protection as above should be provided.

Also, a store where the most sensitive spare parts are provided is mandatory. As an example, IMCA R 006 says that major or critical spares such as those listed below must be available in sufficient quantities:

- Tether
- Slip ring unit for winch
- Slip ring unit for TMS or garage
- Thrusters complete lateral
- Thrusters complete vertical
- Thruster motors complete
- ROV electric motor
- ROV main hydraulic pump
- ROV auxiliary hydraulic pump
- TMS drive motor
- Compensator complete
- Complete set of serviceable PC boards
- Main system computer
- Set of connectors and cables at or above standard quantity
- Rotary actuator or pan-and-tilt unit
- Spare hydraulic hoses, or the facility to make up assemblies as required
- LARS HPU motor and pump
- LARS gearbox
- Spare cameras
- Spare lights for ROV and TMS
- Optic fibre and electrical termination kits

An inventory system that allows locating the spares should be available. Most teams use specific software for this purpose and regularly edit lists that are printed.

Additional spare parts to those listed by IMCA may be provided according to the detected weaknesses of the machine.
It is the responsibility of the ROV supervisor to ensure that the sensitive spare parts are on board in sufficient quantities, and the responsibility of the manager of the ROV department of the company to list them according to the failures detected through the planned maintenance system and according to the recommendations of the manufacturer.

6.3.12 - ROV audit

6.3.12.1 - Purpose

The planned maintenance system allows making sure that the ROV is correctly maintained. However, this system is not sufficient to ensure that the ROV is in perfect condition and fits the best standards. For this reason, it is common to thoroughly audit the system to detect parts of the system that do not conform to the best practices and need to be improved.
Also, the audit is a document the contractor can use to prove to the client that the equipment proposed for the project is in perfect condition. It is the reason most clients require this document.
Note that this audit can be performed internally by the ROV team or by a third party auditor, which is the solution usually selected by the clients. IMCA says that the audit should be performed in the following circumstances:

- Before mobilization or load-out from the onshore facility;
- Following mobilization but before offshore operations;
- During operations, for example, onboard a host installation or vessel.

In most cases, the client requires that this audit is performed before or during the mobilization and every year for systems used on long term projects or integrated into the ship. Thus, because the rule for a diving system is to perform an audit every year and at each mobilization, we can say that the one for an ROV should be the same, particularly for the machines that are involved in diving support.

6.3.12.2 - IMCA audit R 006

IMCA (International Marine Contractors Association) has developed the "Standard ROV Audit Document R 006 " to provide the members of the association a procedure of auditing that is easy to implement. This document, which is also employed by companies and organizations that are not affiliated with IMCA, can be downloaded at this address: https://www.imca-int.com/publications/164/standard-rov-audit-document/.
This guideline explains the following topics:

- ROV System Audits: Background and Rationale
  This point explains when and by whom the audit is to be performed *(it is the point explained above)*.
- ROV System Audit Process
  This point details procedures for:
  - Planning the Audit - IMCA says that the audit should be planned in advance and the document prepared in such a way that anticipates the scope required by the audit and its originator.
  - Assessing - IMCA explains that the audit must not be subjective, but answer to questions which answers should be "yes", "no", or "not applicable".
  - Recording and Reporting - IMCA says that the report should be unambiguous and recommends to classify the findings into the following categories:
    - "Category A" is an unacceptable non-conformity that requires immediate corrective action.
    - "Category B" is a non-conformity that can be addressed within an agreed and practical timescale.
    - "Category C" is an observation in which corrective action is at the discretion of the owner of the ROV.
  - Closeout - The guideline says that what is important is that the findings of the audit are actioned and a formal closeout agreed.
- Competence
  This point explains the profile of the auditor that should conform to IMCA's definition of competence, which is: *"The combination of appropriate training, current skills, knowledge, and experience so that a person consistently applies them to perform tasks safely and effectively. Other factors such as attitude and physical ability can also affect someone's competence"*.
  Note that the guideline recommends that the auditor is at least ROV supervisor, or has a level of competence that is appropriate to undertake such an audit. This point refers to the guidance IMCA C 005.
- Sample Template
  A template, which is designed to most ROV systems, is provided in the appendix of the document. IMCA R 006 says that a lot of service providers and contractors have their own ROV auditing process and that this template is provided as an example for members who have not such a process in place and need to implement it. This audit template that is organized under the form of questions to which the auditor answer as explained above covers the following:
  - Audit overview and executive summary;
  - General ROV system information;
  - Control room or container;
  - Workshop including system spares;
  - Deployment system (LARS, winch, HPU, etc.);

- ROV;
- TMS;
- Support analyses, documentation and procedures;
- Optional functional wet test;
- Detailed audit findings.

- References
  This point indicates the following documents that are downloadable at this address: https://www.imca-int.com/divisions/rov/publications/
  - IMCA R 004 – Guidance for the safe and efficient operation of remotely operated vehicles
  - IMCA R 005 – Guidance on safety procedures for working on ROV high voltage equipment (above 1kV)
  - IMCA R 008 – Terms and conditions for ROV support services
  - IMCA R 009 – ROV mobilisation
  - IMCA LR 011/IMCA R 011 – The initial and periodic examination, testing and certification of ROV launch and recovery systems
  - IMCA R 013 – Contract for the provision of ROV, support vessel and associated work
  - IMCA R 015 – Code of practice for the safe use of electricity under water
  - IMCA R 021 – Remotely operated vehicle load testing and inspection
  - IMCA C 005 – Guidance on competence assurance and assessment: Remote Systems & ROV Division

6.4 - Preparation of the ROV for diving support

6.4.1 - Organization of the team

6.4.1.1 - Minimum team and qualification

The duties of the ROV team is explained in point 3.2.

IMCA and NORSOK consider that a minimum crewing level of three per shift is necessary for a class 3 ROV and can be reduced to two people for ROVs class 2 and 1.
Also, it is recommended that the members of the team have complementary skills and sufficient hydraulic and electrical knowledge to be able to maintain the machine.
The ROV supervisor should ensure that there are sufficient personnel for the launching and the recovery of the ROV.
Besides, it may be necessary to have specialised personnel for operating additional sensors and equipment if other tasks than divers assistance are planned.

Organizations require that the members of an ROV team have minimum experience and training to be accepted to an upper level of their position. As an example, the table below summarizes IMCA and NORSOK requirements:

Requirements IMCA	
Position	***Experience***
Pilot grade 2	Entry level
Pilot technician grade 2	Entry level
Tooling technician grade 2	Entry level
Pilot technician grade 1	- 180 days offshore as pilot grade 2 - 100 hours piloting of which 40 hours can be on simulators.
Tooling technician grade 1	- 180 days offshore as grade 2
Senior pilot technician	- 360 days offshore, and 100 piloting hours as grade 1
Senior tooling technician	- 360 days offshore as grade 1
ROV supervisor	- 180 days offshore as ROV Senior Pilot/Technician + assessment competencies
Tooling supervisor	- 180 days offshore as ROV tooling technician + assessment competencies
ROV superintendent	- 180 days offshore as ROV Supervisor + assessment competencies

Requirements NORSOK	
Position	**Experience**
Pilot	Entry-level - 9 days training course in a specialized school with 5 hours simulator + two weeks offshore with an ROV system
Pilot technician	ROV pilot level + 200 hrs experience with relevant ROV operations + 5 days training course in a specialized school
ROV supervisor	3 years Experience as ROV Pilot/Technician
ROV superintendent	2 years as ROV supervisor

Regarding this point ADCI says that the qualifications of ROV personnel are determined by training, experience and actual evaluations of the individual by the employer.

The petroleum companies usually ask that ROV teams operating on their oilfields have an experience that is above the minimum required by organizations above. The table below is an example of what they commonly request.

Position	Experience
Pilot technician	Proof of competency + three years experience
ROV supervisor	Proof of competency + five years experience with ROV offshore operations with a minimum of three years experience from a DP vessel as ROV Pilot.
ROV superintendent	Ten years experience with ROV offshore operations with a minimum of five years experience from a DP vessel as ROV Supervisor.

6.4.1.2 - Shift and piloting periods

IMCA and NORSOK say that the working time of ROV personnel is limited to 12 hours followed by a rest period of the same duration. We can say that this rule is recommended by all safety organizations.
IMCA also says that the maximum number of hours that a member of the ROV team pilots an ROV should not exceed six hours in every 24 hours under normal circumstances. The assistance of the pilot, the launching and recovery of the machine, and various maintenance works, are parts of the other tasks pilot technicians perform during their shift.
A meal break of one hour in the restaurant of the ship should be organized at approximately the mid-shift period as well as refreshment breaks that can be taken at the work station. Also, facilities such as toilets should be at the proximity of the ROV station.
It may happen that for operational reasons or unfavourable weather conditions the working periods indicated above cannot be applied. Regarding this point, IMCA says:
Members of the ROV team should not be asked to work or be on standby for more than 12 hours without having at least eight hours of unbroken rest during the previous 24 hours. However, in some circumstances an ROV team may have been on standby for a number of hours before an operation begins and, in such circumstances, this can be taken into account in extending the hours worked. In such cases, extreme care should be taken and allowance should be made for the effects of fatigue.
Based on the above rules, the ROV manager must ensure that sufficient qualified and experienced personnel are available at all times to be able to face any problem that may happen.
Also, extended work periods should be performed exceptionally, and not become a habit. So such a situation should be limited to two days maximum followed by a long period of normal working conditions (> 2 weeks), except in conditions where lives that are threatened depend on the intervention of the ROV.

6.4.2 - Elements to take into account when preparing the risk assessment

6.4.2.1 - Electricity

Note that the effects of electrical shocks in the water and at the surface are explained in Book #4 “diving accidents” of this manual.

ROVs are powered by electricity flowing through its umbilical, connection boxes, and equipment, which a leakage may harm the diver at different degrees, depending on whether he is in the sea or freshwater.
“Conductivity” is the measure of the ability of fluids and solids to pass an electrical current. Note that the ability to carry current is better at warm than at cold temperatures.
The distilled water does not contain dissolved salts and it does not conduct electricity. Thus, the conductivity of water is

dependent on the presence of inorganic dissolved solids such as chloride, nitrate, sulfate, and phosphate anions (ions that carry a negative charge) or sodium, magnesium, calcium, iron, and aluminium cations (ions that carry a positive charge). Because the sea has about 3.5% of dissolved salt in addition to other particles, it has a low electrical resistance. In contrast, fresh water, depending on the particles in suspension, has a relatively high electrical resistance, so, a low conductivity.
Referring to what is indicated, a leak of electricity in salt water will be transmitted to the ground, and a leak of electricity in freshwater will not easily pass to the ground. As a result, a diver in saltwater should feel the electrical field before being affected. Three progressive states are commonly described:

1. The diver starts to feel the electrical field, and this sensation becomes more potent as he goes closer to the source to become uncomfortable progressively.
2. A more harmful problem can be a diver caught in an electrical field sufficiently powerful to cause some of the muscles to contract involuntarily. This phenomenon that is commonly called “let go level”, is known to result in the inability of the person to open the hands and move. That is not considered very hazardous if the current is switched off immediately. However, that may become harmful if the breathing muscles are contracted during a too long period. In saltwater, such effect may happen if the fault develops when the diver is in its direct vicinity, or if he continues to approach despite the warnings of state #1.
3. The most severe effect is an electrical emission that causes fibrillation of the heart (fibrillation is a rapid, irregular, and inefficient beating of the heart), which results in the blood not circulating anymore. As above that may happen if the diver is at the direct vicinity of the fault when the problem starts, or if he continues to approach despite the warnings of state #1.

Opposite to saltwater, the diver in freshwater may not feel the electrical field and may become the link to the ground if he enters it as the human body is composed of salted fluids through which the electric current can find its path to the ground. As a result, he may be in scenarios #2 and #3 without any notice.

There are some technical considerations to take into account regarding ROVs, such as the fact that the primary power is derived from the vessel’s 400-480 V/ 50-60 Hz AC that is stepped up through an isolating transformer to provide up to 3000 volts to the machine via the umbilical. This current supplies the motors of the thrusters or the motor of the hydraulic pump that activates them, depending on whether the thrusters are electric or hydraulic. Depending on the model of ROV, other separate electrical supplies may be provided to supply the lights and other functions. These supplies are monitored by Line Insulation Monitors (LIM), connected to an alarm, and other protection devices *(see the explanations below).*

1 - Step-up isolating transformer

2 - Line Isolation Monitor (LIM)

3 - Circuit breaker

4 - Current up to 3000 volts

5 - Umbilical to ROV

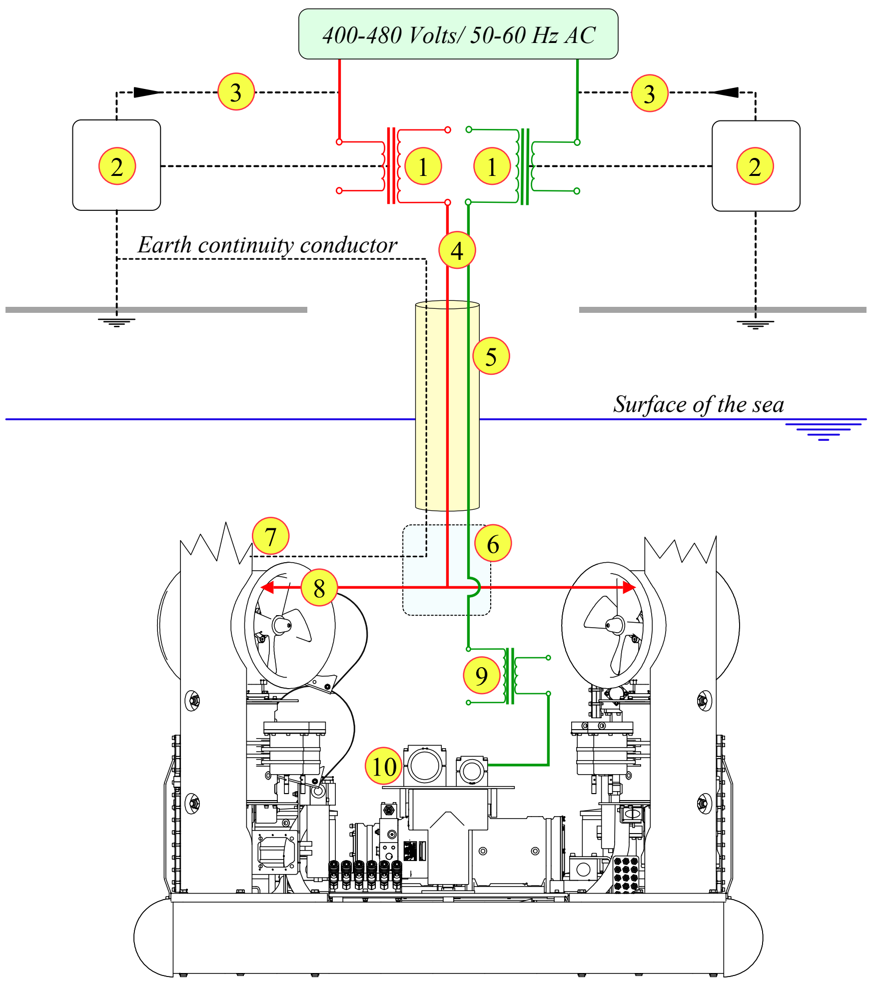
6 - Distribution box

7 - Earth connection

8 - Supply to thrusters' motors or pump

9 - Step down transformer

10 - Lights 120 volts (or low voltage)



Regarding the line protection device indicated above and similar systems, note the following:

- A Line Isolation Monitor (LIM) is a device that continuously monitors the integrity of the insulation between live conductors and an earth return circuit to provide a status of the insulation. It triggers an alarm and cuts out

the supply if the insulation value falls below a set level.
IMCA R 0015 / D 0045 says that the response time of some devices may be too slow to protect the divers. Also, because of the length of cable, there may be the possibility of a high charge being stored in the umbilical and the circuits monitored, which can therefore be potentially harmful to a diver.

- A Residual Current Device (RCD), also called Residual Current Circuit Breaker (RCCB), or Ground Fault Circuit Interrupter (GFCI), is a device that compares the current between the supply and returns lines of a circuit to detect earth-leakage. If a difference is detected, the equipment quickly breaks the electric source to prevent electric shock.
- A trip unit is the part of a basic circuit breaker, RCD, or LIM that opens the circuit in the event of a thermal overload, short circuit, or ground fault. These devices have different response times that depend on their function. Based on CEI/IEC/TS 60479 studies, it has been considered that systems designed for short circuits or ground fault with an operating time of 20 ms or less provide an acceptable response.

IMCA R 015/D 045 is a document that has been published to provide guidelines regarding the safe use of electricity underwater. These guidelines, that are based on the publication CEI/IEC/TS 60479 from the International Electrotechnical Commission, mostly discuss dives at sea. Nevertheless, the document indicates the problems that may arise from fresh water.
This guidance provides an analysis of several devices used in the offshore industry, among which ROVs, that is based on the Ohm law: *Safe voltage = Safe body current (mA) x Body Resistance (Ω - ohms).*
Note that the result of this calculation is expressed in millivolts that must be converted to volts. Also, based on the results of experiences explained in CEI/IEC/TS 60479, the following values are selected:

- The body resistance is 500 ohms for voltages over 50 ohms and 750 ohms for low voltages (< 50 ohms)
- 500 mA is considered a safe value of current

Based on these calculations, IMCA provides tables, which the one dedicated to ROVs gives the following results that can be used to visualize harms linked to electricity with such a machine:

Description	***Safe body current in milliamperes (mA)***	***Body resistance in ohms (Ω)***	***Safe maximum voltage in volts (V)***	***Safe nominal voltage in volts (V)***
Alternating current with trip device.	*500*	*500*	*250*	*220 (See in notes*)*
Alternating current fed from an isolating transformer with a non-earthed secondary. Using a LIM with circuit breaker.	*Not applicable*	*Not applicable*	*In this case, a single fault does not present a hazard and thus no maximum voltage needs to be stipulated provided the protective devices are able to prevent the occurrence of a second fault constituting a hazard.*	
Alternating current fed from an isolating transformer with the secondary earthed through an impedance to limit fault current to 1A and trip device.	*Not applicable*	*Not applicable*	*No voltage limit is stated as the diver is protected by the fault current limit and the associated trip device.*	

Notes *:

- The nominal voltage is the specified system voltage of the supply circuit to which a device may be connected.
- IMCA says that the values of safe distance in water depend on the ratio of fault current (I_o) to the safe body current (I_b), and that the approximate safe distance in sea water (Ss) in metres is calculated according to the following formula: $S_s = (I + \{(I_o \times 10^{-4})/ I_b\})^{½} - I$.

It must be noted that even though the guideline above provides a useful means of analysis, the method proposed has its limits and should be employed as a means of reflection instead of a precise means of calculation for safe distances:

- Calculations with the formula given above can be corrupted if some values are inexact.
- It is difficult to evaluate in advance the amount of current leaking in the eventuality of a fault occurs, and it is not prudent to base such a calculation on a minimum leakage. Also, note that using a machine that is known not to be utterly isolated is not an acceptable practice.
- People working in deltas and their vicinity may operate in waters in which salinity varies at all times. Regarding this point, it must be remembered that deltas of large tropical rivers have an influence on the environment at distances that are up to 200 km from their mouth. That often results in layers of salt and fresh water crossing.
- The evaluation of the safe distance is a complex process that should be performed by trained and experienced people only. However, even though the calculations produced may give results close to reality, the uncertainties described above cannot be removed entirely.

Using the elements above, elements such as those listed below should be taken into consideration:

- The electrical power supplied to the ROV and how this supply is monitored and controlled should be documented. An isolating transformer with the secondary earthed through an impedance to limit fault current to 1A and a trip device must be in place and be able to respond within 20 milliseconds or less.
- Electrical shock protection devices should be tested before each ROV dive, and warnings stickers provided.

- Calculations of the possible electrical leakages and the safe distances from the machine should be provided by the ROV manufacturer or a recognized specialist and presented in a format that is easy to understand and be implemented by people at work. It must be considered that to be utilizable, a guideline must be easy to apply, especially when complex computations may be the sources of fatal mistakes, and the environmental conditions may frequently change and oblige to review the initial estimate. An example of complex calculations that are made exploitable to everyone is the decompression tables.
- The diver should not have any physical contact with the ROV when the machine is activated. For this reason, procedures such as direct tools transfer to the divers should not be used. Instead, when some tools are to be transferred to the divers, the ROV picks them up and deposits them in a dedicated place where the divers can access when the machine is away.
- In case of a breakdown of the ROV, and a diver is asked to intervene, the electricity must be fully isolated, and the machine checked for residual current before the diver can approach it.
- There is no reason to approach the ROV very close to the divers during diving assistance. The typical closest distance of the ROV from the divers, which is empirically applied by the teams, is approximately 5 m, even though calculations may allow it to be closer. Note that regarding this point IMCA indicates 4 m. This distance is to be increased if an estimate proves that it is too nearby. Note that 5 m is also considered a safe limit to avoid collisions by a lot of ROV teams.
- The ROV should approach the divers very slowly, so an undetected fault can be felt by the divers sufficiently on time in saltwater in addition to avoiding a collision.
- An ROV that is known to have electrical leakage should never be at the proximity of divers: Any electrical fault detected should result that the machine is withdrawn from the worksite, and is sent back only when the problem is repaired. Note that such events must be reported.
- As previously said in point 10.3.7, ROVs operating at the proximity of divers should be equipped with transponder and a flashing light, so the diving supervisor can see where it is on the nav screen, and the divers can also visualise it.

6.4.2.2 - Entanglement & collision

Entanglement may happen with the umbilical of the bell, the divers' umbilicals, the downline, positioning systems such as taut wire, and other lines that may be deployed.

- Entanglement with the bell umbilical may result that the bell, and the ROV cannot be recovered.
- Entanglement with a diver's umbilical may result that the diver can be injured, be unable to return to the bell, and may be drawn at the direct proximity of the ROV that is still active.
- Entanglement with the taut wire of the Dynamic Positioning vessel may result in a loss of position, and the ROV that cannot be recovered.
- Entanglement with downlines and other lines may result that the ROV cannot be recovered.

Entangled umbilicals can be freed by the ROV team when possible, except with divers umbilicals that should be disentangled by the divers. Regarding this last point, IMCA R 020 says that switching power off to the ROV is to be avoided, as without power the ROV could be swept into the diver and cause injury. This guideline says that the ROV monitoring and instrumentation system should give any indication of potential electrical failure and priority to keeping control of the ROV.
For the other scenarios, if the situation is too complicated, the divers may have to intervene to recover the machine.
Note that, as previously said, for divers intervention on the ROV or its tether, the ROV must be stopped and its electrical supply deactivated. The solving of the problem by the divers may result in the ROV umbilical being cut, and the machine recovered to the surface using the crane. In such a case, the ROV team must ensure that there is no residual current, and the ROV must be loaded to ensure that it will not return to the surface unexpectedly.

Collision with divers may result from a loss of control of the machine or the ROV traveling while there is no visibility. Note that collision with lines, debris and structures may also happen.

- A collision with a diver may result in the diver being seriously injured and unable to return to the bell.
- A collision with debris, stricture, or a line may result in the ROV being damaged, or entangled or stuck. Such damages may prevent the ROV from being recovered by itself.

A diver injured and unable to return to the bell has to be rescued. During this time, the ROV must be stopped and de-energized.
An ROV damaged that cannot be recovered may have to be recovered by the divers. In this case, the rules regarding electricity and the recovery by crane have to be in place.

The prevention of entanglement and collision is based on a safe distance between the diver and the ROV:

- The ROV pilot should be aware of all lines and structures in the water, and of the position of the bell and the divers as well as the position of the TMS. A document that explains the worksite configuration should be provided, and the nav screen should be updated.
- There should be a tracking device on the ROV, the TMS, the bell, and the divers to identify their position on the nav screen.
- IMCA says that the launch and recovery of the ROV must be considered a lifting operation, and that appropriate procedures should be implemented. For this reason, the ROV should be sent first and recovered after the dive.

- The ROV deployment system should be situated at the maximum possible distance from the diving bell and taut wire launch positions to minimize the probabilities of entanglement of its umbilical.
- IMCA also suggests that, if possible, the TMS/garage is located within the limits of excursion of the divers such that a diver would not be carried beyond his excursion limit should he become entangled with the ROV tether.
- The positioning of the ROV related to the divers and the bell should be taken into account in case of a total break down of the machine. For this reason, it is preferable to position the ROV downstream and away from obstructions.
- Note that the ROV should be static when the divers go outside the bell and the divers aware of its position. However, it is recommended to keep the divers in view.
- There must be a strobe light on the ROV to indicate visually its position to the diver. A good practice is also to turn on the lights. The ROV pilot must also see the divers. For this reason, he may have to dim his light and require the divers having their helmet lights on. It is also a common practice to flash the divers' lights.
- The thrusters should be fitted with guards to prevent the ingress of a diver's fingers, umbilical or equipment.
- The ROV should not, for any reason, be flying in a no-visibility situation with a diver in the area.
- The intervention of the ROV is authorized by the diving supervisor only, who needs to be informed of the intention of the pilot. Also, the ROV moves must be indicated to the divers.
- Five metres from the divers is considered a safe limit to avoid collisions by a lot of ROV teams, as already said, IMCA authorises 4 metres. Five metres is also the distance below which the supervisor loses any panoramic view of the divers. Note that when the ROV is at this limit, zoom cameras can be used to see more details. Also, as indicated above, the ROV should approach the divers very slowly, and the divers must be aware of it.
- Uninterrupted communications must be established with the dive control, the bridge, and the survey team.
- The ROV tracking device should not be used as a reference of the positioning system of the vessel.
- Members of the diving and ROV teams should be aware of the hazards and operational constraints of simultaneous operations.

6.4.2.3 - Environmental conditions

Variations of the environmental conditions may affect the ROV operations or prevent them from starting:

- Variation of the salinity of the water may affect the buoyancy of the machine. That commonly happens in estuaries where layers of saltwater and freshwater superpose.
- In addition to the change of buoyancy, the variations in salinity is known to affect the acoustic tracking and positioning systems. It is also the case of differences in temperature and parasite noises.
- Reduced visibility may affect the operations and may oblige to keep the machine in the TMS. Also, activities near the seabed may stir up fine sediments that remain in suspension and reduce or erase visibility. However, some ROVs can be equipped with Imaging SONAR enabling a photographic type view of the sea bed; Such a system can allow the ROV to move in an environment where the visibility is reduced and perform some simple tasks.
- Saturation diving support is usually performed at depths that are unaffected by the weather conditions at the surface. Thus the main problem is the deployment of the ROV over the side of the vessel. Note that DP vessels can be positioned to protect the launching stations when they are not alongside facilities that may reduce their capacity to change their heading. Such possibility is not available with barges and four-point mooring ships which movements are limited by their mooring.
  In the case of shallow saturation dives, the weather may affect the water layers nearby the surface, and the ROV may not be able to fly correctly.

The fundamental rule to apply is that when the ROV is the only means for the rescue of the bell, the dive must not be launched if the ROV cannot be used adequately to rescue the bell safely.

6.4.3 - Documents that should be onboard

Clients require that documents such as those listed below are on board. Note that, depending on the client, more items may be asked.

- Proof of competencies of ROV team members.
- Quality Assurance (QA) and Health, Safety, and Environmental (HSE) manuals.
- Technical manuals for the ROV system, including the additional sensors and tools used.
- ROV project plan with the task plans for all activities of the relevant contract and their risk assessments.
- Emergency response plan for the project planned.
- Build certificates for the ROV system main components.
- Valid Lifting certificates (rigging and machine).
- ROV audit IMCA R 006 or similar *(see point 10.3.11.2)*.
- Calibration certificates for all sensors.
- Operational activities logs.
- Planned maintenance system *(see point 10.3.10)*.

Note that the emergency response plans, working procedures, and task plans should be published sufficiently in advance to let the team study and discuss them and that in case changes are necessary, the management of change procedure can be followed.

6.5 - ROV operations for surface supplied diving support

6.5.1 - Chain of command

The elements regarding the authorities, which some are indicated previously should be clearly established and understood by people involved, so an efficient chain of command is in place:

- The diving supervisor has authority over the ROV supervisor (and the pilot) when simultaneous operations are being carried out.
- Related to above, the ROV should be deployed only when authorized by the diving supervisor and the bridge (or the OIM control room) while diving operations are in progress.
  ROV movements must be allowed by the diving supervisor and passed to the bridge.
  The ROV can leave the worksite only when it is authorized to do so by the diving supervisor.

6.5.2 - Elements to consider in the checklist

Safe practices impose to check any equipment intended to go in the water, and particularly those used for diving support. These checks must be performed before each dive.
The ROV and its Launch And Recovery System (LARS) must be strictly inspected before turning on the power supply to detect potential or existing problems. This inspection focuses on structural issues such as cracks or unsecured elements, in addition to a close check of the junction boxes, slip rings, cameras, connectors, lights, etc. Then the vehicle is powered, and the commands are controlled as well as alarms, data displays, lights, and cameras. In addition to usual checks, the ROV team preparing a dive support operation should focus on the following vital elements:

- The devices that must be in place to protect the personnel against electrical shocks should be tested. Regarding this point, IMCA says that the Line Insulation Monitor (LIM) systems should be physically tested and recorded as part of the pre and post dive checks and repeated on a 24 hourly basis during long dives when supporting diving operations.
- Also, the tools that may have to be used and are described in point 10.3.8 should be checked and function tested. Note that other tools than those described in this point, which are the minimum to be provided, can be used. It is the case of inspection tools, specific manipulators, etc.
- Localization tools such as beacons should also be tested, and their batteries should be full. The surveyors are responsible for the calibration and the batteries of these devices.
- Regarding the buoyancy of the ROV, IMCA recommends that it is ballasted negatively buoyant to eliminate the risk of divers being moved out of their excursion range by the ROV returning to the surface in case of a total break down with their umbilicals entangled. This buoyancy should be adjusted such that the ROV trimming does not require excessive thrust to maintain position or manoeuvre in the water column.
- The thruster guards should be closely inspected as well as the cables and hoses that may come into contact with the divers that must be secured.
- The thrusters should also be function tested and checked for oil leaks, the presence of fishing lines, shocks, etc.
- The operational procedures should be understood by the ROV team.
- The diving supervisor must ensure that the ROV team understands the emergency procedures for recovering the diving bell/basket.
- The procedures for the recovery of the ROV should be understood by the diving staff.
- As previously indicated, the communications with the dive control and the bridge, and also those to the survey team, must be carefully checked with the Dynamic Positioning alarm system (if used)

6.5.3 - Organization of diving support operations other than diving bell rescue

ROVs are employed to various supporting tasks during a diving project that are not limited to only diving bell rescue, and it is the responsibility of the Offshore Construction Manager and the diving superintendent to organise such operations that must be indicated in the diving project plan.

6.5.3.1 - Operations with two ROVs

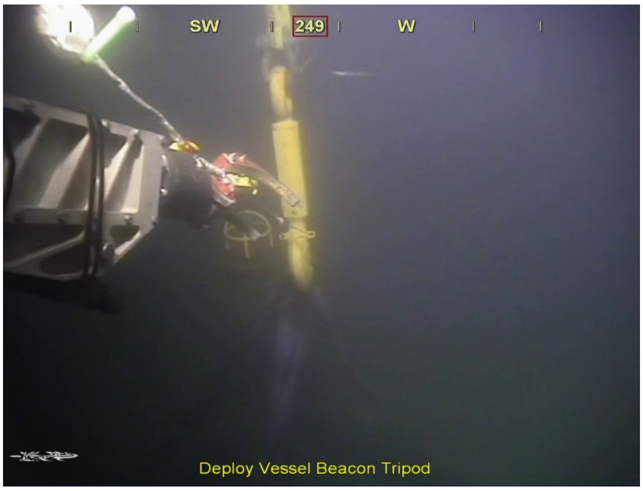
Depending on the project plan, a second machine may be planned for the project.
If the 2nd ROV is a class 2, it is preferable to use it to monitor the dives as these machines are less dangerous in case of a collision with a diver than a class 3 ROV as the result of the difference of mass and power.

If it is planned to employ a machine to simultaneous tasks, they must be organized not to conflict with the diving job scheduled, and the chain of command indicated in section 6.5.1 is to be applied:

- The diving supervisor has authority over all ROV supervisors and pilots.
- The ROVs must be deployed in the water before the bell and recovered to the surface after the bell. This procedure, which is already indicated in section 6.4.2.2, is to avoid an ROV deployment above the divers and the bell.
- The launching station of the ROV used to monitor the divers should be the closest to the bell and the diving worksite. Also, the launching station of the ROV planned to perform the simultaneous task should be sufficiently far from the other stations to avoid conflicts such as umbilicals entanglements.
- The worksite of the ROV should not be upstream of the worksite of the divers. Also, this ROV must be ballasted negatively buoyant as the ROV used for the surveillance of the divers for the same reasons.
- Direct communications must be installed between the 2nd ROV station and the dive control and the bridge. Also, displays from the 2nd ROV should be provided in the dive control and the bridge.

6.5.3.2 - Acoustic transponder installation

When the project is planned to use acoustic positioning, the ROV is usually employed to install the transponder and remove them at the end of the operation. The installation of the transponders is normally performed using the crane, as surface positioning systems have to be used for a precise localization. Thus the operation performed by the ROV is to disconnect it from the frame that holds the beacon. However, if the ROV is sufficiently powerful, it can be used to recover the transponders at the end of the project or if the device must be changed. For this reason, it is an advantage of having a powerful ROV instead of one that is too limited in power for these tasks.
Note that it often happens that vessels are provided with only an observation class ROV that is only used to perform inspections and monitor the divers. In this case, transponders can be installed by another vessel equipped with work class ROVs. This organization of the job may pose problems of scheduling that may impact the project, as the Diving Support Vessel is dependent on the availability of another ship. It is also common to lower the transponder to the seabed using a davit or a crane. In this case, the vessel's movements will be restricted by the cable securing it.



Beacon installation: Disconnection from the crane

Beacon recovery using the 5 functions manipulator

6.5.3.3 - As-found and as-built surveys

These inspections were previously commonly done by the divers, and it can be the case today. However, a lot of teams prefer using the ROV, because it avoids exposing lives when there is a risk of hydrocarbons or other dangers.
Also, a lot of clients require as-found and as-left inspections performed by ROVs instead of divers for the safety reasons indicated above and because some elements they may use, such as the depth, altitude, heading, the geographical position, and others are displayed on the screen.

As found survey: General view of the structure

As found survey: Detailed view of the structure

6.5.3.4 - Bell/basket checks

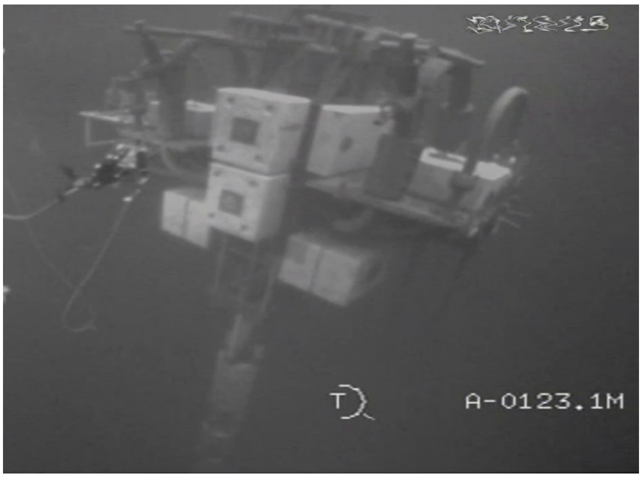
The inspection of the bell/basket at its arrival at depth and before its recovery is a standard procedure.

1. The ROV is launched to the worksite first and waits for instructions in the TMS or near the worksite.
2. When the clump weight of the bell is deployed *("clump weight" is explained in section 2.3.2.2 "Anti gyration systems" of the document "Description of a saturation system")*, the diving supervisor asks the ROV pilot to check its position and whether it is sufficiently far from obstructions.
3. At the end of the inspection, the ROV returns to the TMS or stay in a safe place (it should be downstream), waiting for instructions.
4. When the bell is launched, the diving supervisor asks the pilot to position the machine near the clump weight to monitor the arrival of the bell/basket at depth. The ROV gives a visual of the final descent of the bell/basket and the distance of the bell to its clump weight (which is also confirmed by the divers).
5. When a wet bell is used, the ROV quickly inspects the dome and the main umbilical before returning to the safe place from which divers in and outside the bell/basket can be observed. This inspection should not interfere with the launching of the divers that usually happens upon the arrival at the working depth due to the limited bottom times allowed for surface-supplied diving operations techniques.
6. At the end of the dive, the supervisor asks the pilot to position the machine near the bell/basket to ensure that it can be safely recovered (this inspection is also made by the divers). The same process is to be used to retrieve the clump weight at the end of the diving operations.
7. When the clump weight is retrieved, the ROV can return to its TMS and being recovered to the surface when authorized to do so.

6.5.3.5 - Divers observation

The observation of the divers is performed between tasks 5 and 6 discussed above.
The advantage of using the ROV to observe the divers is that it gives a panoramic overview of the scene, and thus a better appreciation of the situation to the diving supervisor. That allows seeing dangerous conditions that may not have been detected by the divers, so making sure that they work in a safe condition at all times.
Also, the diving supervisor can ask the ROV to approach within the maximum safe limit when he needs to have a more detailed view of the operation ongoing *(see below)*.

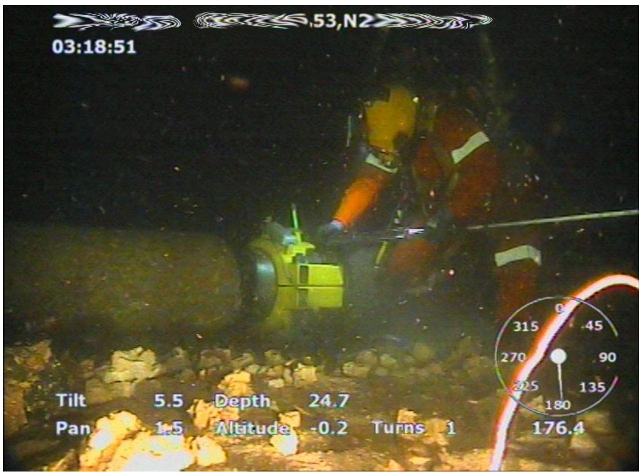
Close view of divers during a load transfer



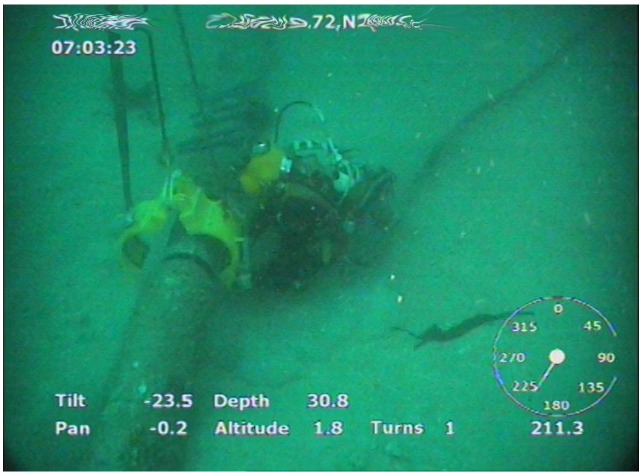
Panoramic view of the worksite

Note that the ROV can be used to light up a diver. Also, when working near the seabed for long periods, it is preferable to sit the ROV on it instead of flying around the divers *(see the photos below)*.

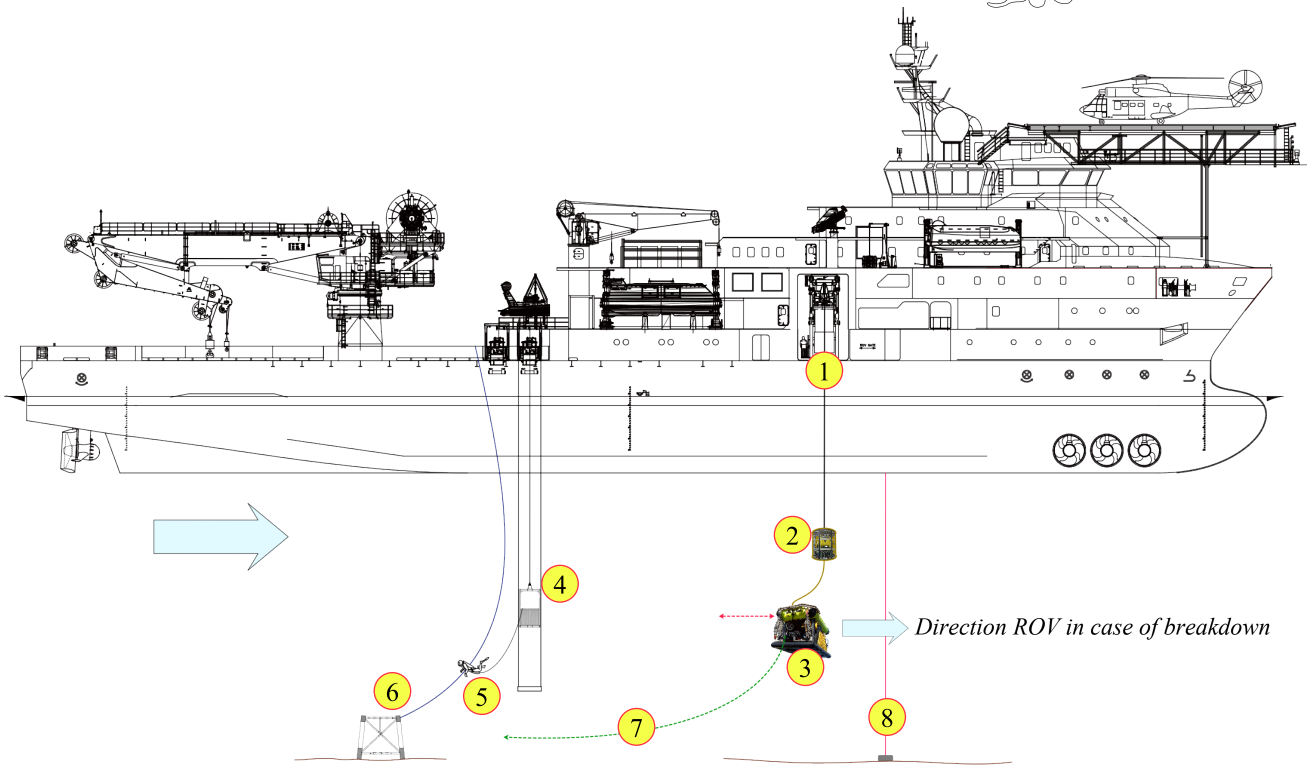
Important: The precautions listed in point 6.4.2 must be in place and always taken into account during these operations.



ROV sat on the seabed lighting up a diver (see Altitude = 0)



Panoramic view of a load transfer



1 - Launching station ROV	*Situated starboard side in this example. It should be the closest station to the job site*	*5 - Diver*	*Equipped with a beacon, a helmet camera + a helmet light. Closest distance to ROV = 5 metres.*
2 - TMS	*Equipped with a beacon and a warning light.*	*6 - Worksite & downline*	*They must be indicated on the nav screen.*
3 - ROV	*Equipped with a beacon and a warning light, + adjusted negatively buoyant. Closest distance to divers = 5 metres Positioned downstream of the job site.*	*7 - Travelling ROV to the worksite*	*Travelling on the starboard side of the bell and the tending point, and sufficiently far to not be entangled with the divers and any deployed device.*
4 - Diving bell or basket	*Equipped with a beacon and a warning light. Deployment through a moon pool at the center of the ship*	*8 - Taut wire positioning system vessel*	*Deployed from Portside in this example (the other side) for not being in the way of the ROV and being entangled. It must be indicated on the nav screen.*

6.5.3.6 - Precautions to be in place when working with a new ROV team or pilot

It is usual that the ROV contractor employed on the diving project is a sub-contractor of the diving company or that a trained pilot used to work with the diving team is replaced by another one.
As already discussed in point 6.4.1.1, clients usually request minimum experience and training. However, what is written on logbooks is one thing, and the reality can be something else.
For this reason, when new people are employed, it is prudent to limit the approach of the ROV to the divers to 10 metres during the first dives to ensure that the machine is entirely under control. After evaluation, the new pilot can be authorized to approach at 5 metres when asked for by the diving supervisor.