

Underwater mines disposal

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Content

1. Introduction	1
2. Solutions	1
Sucess of stealth remotely operated vehicles (ROV)	1
The PAP: identifying & neutralising mines	2
The minekillers	3
Non-stealth ROVs	4
New neutralisation devices	4
A challenging scenario : preparation for amphibious operations	5
3. Implementation	6
4. The future	6
5. Conclusion	7

1. Introduction

DEVICES CAPABLE OF DAMAGING SHIPS ARE CLASSIFIED AS UNDERWATER THREATS

Mines as main underwater threats

Mines represent the majority of these threats since their objective is to at least damage ships, at most to sink or destroy them completely.

Yet there are also remnant **bombs** dropped during World War II, not to mention those dropped during more recent conflicts. They become a threat when found at the bottom of a harbour or in a fishing area since **their explosive material can still be active despite decades spent in seawater**; they may also have become unstable over time, which makes them potentially even more dangerous.



THREAT DETECTION AND DESTRUCTION: TWO DISTINCT AND COMPLEX OPERATIONS

Though it is a complex matter to detect remnant underwater mines and ammunition¹ lying on the bottom of an ocean, it is equally complex to have sea divers destroy them due to **environmental constraints** (e.g. sea currents, water depths, etc.) and to the **effects of any underwater explosion**.

This led naval forces and the industry worldwide to develop systems designed to reduce the risks associated with neutralising such threats while optimising the effectiveness of such disposal operations, i.e. destroying the largest possible number of threats in the shortest possible time.

2. Solutions

SUCCESS OF STEALTH REMOTELY OPERATED VEHICLES (ROV)

One of the first effective systems built to eliminate underwater threats stemmed from **France's ambition to develop its own nuclear deterrent weapons delivered by submarines**.

With its nuclear powered ballistic missile submarines (SSBN²) based in the Brest roadstead, the French Navy had to be able to **detect and destroy any underwater threats on the access routes of these submarines to make its deterrence concept credible**.

¹ Known as unexploded ordnance (UXO)

² Abbreviation for "Strategic Submarine Ballistic Nuclear"

THE PAP: IDENTIFYING & NEUTRALISING MINES

Mine-hunting sonars and **Q-route survey sonars** were thus designed to detect these threats, as was the **self-propelled undersea drone or 'PAP'**³ concept, which can be used to identify mines and lay explosive charges next to them, even under difficult environmental conditions.

Thanks to images taken by the **PAP vehicle's camera** and transferred via a cable link, a human operator onboard a ship at a safe distance from the threat can guide the PAP with a joystick and lay the explosive charge near the mine so it can be disposed of safely.



This explosive charge is activated by an operator using an **acoustic signal** so its explosion in turn triggers the explosion of the mine⁴.



Exail PAP MK6 ROV : « Poisson Autopropulsé » latest generation of "Self-propelled fish"

A design adapted to weather conditions

This self-propelled undersea drone called PAP has proved successful with many navies⁵ because of certain design choices:

- Integration of a **rechargeable electric battery** to eliminate the need for an umbilical cable to power the vehicle which restricts its manoeuvrability in sea currents owing to its drag force. It was essential to remove this cable so the vehicle could **travel several hundred metres from the ship** from which it is deployed, **at depths up to 300 m** and in **currents sometimes exceeding 3 knots**.
- Development of propulsion units with **low magnetic radiation** enabling the unmanned vehicle to come close to influence mines that detonate when they detect a change in the local magnetic field.
- Incorporation of a **bobbin of very thin cable** for communication between the unmanned vehicle and its operator. This cable unwinds from the vehicle with the current - as is the case with certain torpedoes - and **cancels out the impact of the cable's drag on the vehicle**.
- Use of a **"guiderope"** to maintain vehicle navigation at a constant altitude above the seabed without requiring sensors, actuators or predictor functions.

Today, the PAP would be described as a stealth vehicle, i.e. a **vehicle with sufficiently low magnetic and acoustic radiation** enabling it to be brought close to a mine with a very low probability of triggering it, thus making it possible to identify the mine and lay an explosive charge so it can be detonated.

The PAP is perfectly suited for neutralising mines lying on sea beds, but is a little less so for moored mines floating below the water surface. The PAP is thus equipped with explosive cutters to handle such mines. The cutters are used to sever the mooring wire. Once the mine has been cut loose, it must then be identified and neutralised with a suitable weapon (machine gun) on the mine-hunting vessel (MCMV).

³ French abbreviation for Poisson Auto Propulsé industrialised by the Exail

⁴ The shock wave generated by the explosive device detonates the mine

⁵ About 500 PAPs have been produced by the Exail and sold to about twenty navies worldwide

Constraints of PAP use

Though the PAP has numerous advantages, it does have some shortcomings. For one, it is **difficult to launch and recover this device from a ship in rough sea state and severe weather conditions**.

It is also only designed to carry a single explosive charge for each operation: neutralising an extensive minefield is a **lengthy process** which therefore requires recovering and reloading the vehicle each time.

Last of all, **it cannot be used to destroy moored mines directly**.

THE MINEKILLERS

Expendable mine disposal vehicles or 'minekillers' were designed to remedy the drawbacks of the PAP.

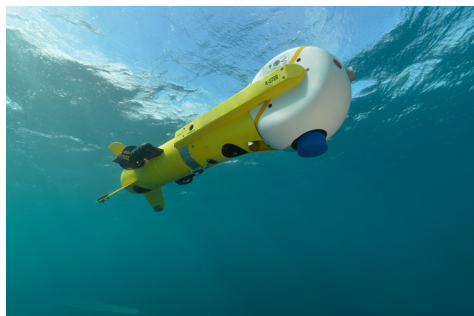
Combat minekillers: Expendable vehicles with shape explosive charge

In its initial combat version, the minekiller was designed to be an **expendable vehicle equipped with a shaped explosive charge**. By design, such vehicles are not meant to be recovered.

Like PAPs, minekillers are connected to the mine-clearing ship or surface platform via an **optical fibre** and steered towards the mine by an operator.

In this case, however, the mine is not neutralised **by laying a 100 kg explosive charge** but by detonating the shaped charge equipping the front part of the minekiller.

When the minekiller is aimed at the mine, the shaped charge intercepts the explosive part of the mine and triggers its explosion, which also destroys the minekiller.



Exail's minekiller (neutralising ROV): K-STER C

By design, the combat mine killer does not need to be a stealth device: when the mine detects the magnetic field, it can trigger the explosion of the mine, which is the objective. Nevertheless, **special attention must be paid to the mine's magnetic signature** if it is brought on board as it can disturb the minesweeping ship's own magnetic signature

For **security reasons**, the minekiller is not recovered once it has been launched.

The firing axis as a main issue

There are two main factors affecting the effectiveness of combat minekillers; firstly, the **ability to control the firing axis of the shaped charge**; and secondly the ability **to maintain a precise and stable position very close to the target mine**.

If the firing axis is not precisely aligned with the mine, ideally with the part containing the explosive, **the shot may not be effective, or it may only result in neutralising the mine** (e.g. by damaging its firing mechanism), rather than actually destroying the mine's explosive material.

Two types of minekiller have been developed to overcome this issue:

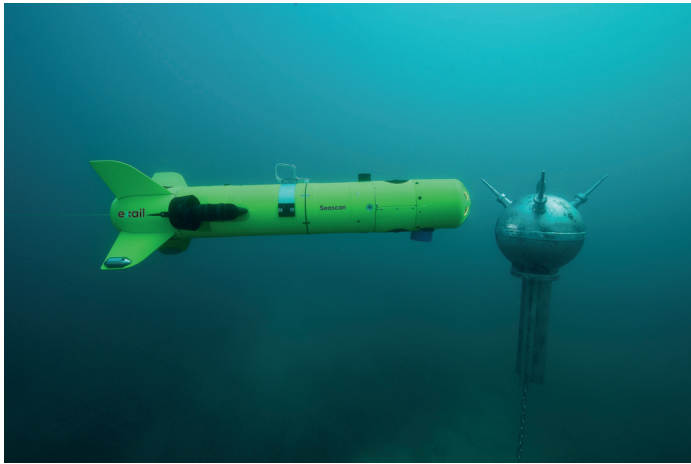
- **Those with a firing axis aligned with the vehicle's longitudinal axis:** this requires a high degree of vehicle manoeuvrability to be able to guide the firing axis, especially in strong currents. This was the initial solution conceived by Atlas and led to the development of the Seafox mine disposal vehicle.
- **Those with a shaped charge that can be tilted up or down in relation to the position of the minekiller and the mine.** This has the added advantage of being able to achieve **precise and stable alignment of the firing axis** in strong currents. This solution was adopted by **Exail** for their **K-STER minekiller**.

Minekillers can prove highly effective against bottom mines, yet they are less effective against moored mines in turbulent currents.

The pull of the current in this configuration can cause the mine's mooring cable and float to swing (caused by strumming effect). The mine killer itself is not subject to the same interactions between the water and the vehicle structure, making it difficult to align the firing axis of the shaped charge with the mine. **Nevertheless, the K-STER is still far more effective in these conditions than the Seafox or other minekillers with similar designs.**

Identifying vehicles : Without explosive charge

As false alarms are not a rare occurrence in the subsea environment, it proved necessary **to design a re-usable identification vehicle, without a shaped charge**, derived from the combat minekiller for the sole purpose of identifying underwater objects or mines before eventually neutralising them. Exail has developed the K-STER I and the SEASCAN for this purpose.



Exail's identifying ROV: SEASCAN MK2

NON-STEALTH ROVS

Whereas minekillers and self-propelled underwater vehicles are essential components for destroying mines, the same cannot be said for **'traditional'** ROVs; these underwater vehicles are **controlled remotely** by an operator on the mother ship **and tethered via umbilical cables from the support vessels or unmanned surface vehicles (USV)** which deploy them.

Although they represent a particularly cost-effective solution, offering the advantages of proven technologies and ease of maintenance (very few consumable parts), in reality they are **only effective against remnant explosives or contact mines in calm waters** for the reasons outlined below:

- **The drag on the umbilical cable does not allow the 'cable + ROV' system to overcome the effects of strong currents.** An increase in motor power for the ROV requires a larger cable, which in turn increases the overall resistance. At the point where this trade-off converges on a feasible solution for realistic environments, the result is a very heavy, cumbersome and inefficient system.
- **The umbilical cable can also transmit movements from the support vessel to the ROV**, which impairs its stability and ability to detect mines and destroy them in rough seas. – Lastly, the motors on traditional ROVs
- which have to be powerful to counter strong currents (typically 3 or even 4 knots) – **generate noise and radiate magnetic fields which can be easily detected by influence mines.** These noise and magnetic field levels increase with the propulsion power of the ROV

Traditional ROVs can nevertheless be used to identify and neutralise unexploded ordnance (UXO) in calm seas..

In contrast to underwater mines, unexploded ordnance is **not equipped with influence firing mechanisms that are likely to be detonated by the radiated noise and magnetic field generated by ROVs.**

Unexploded ordnance can mean any of the bombs from past or more recent conflicts that litter our seas around the world and which turn up in many subsea areas, including cable and pipeline corridors and ports.

NEW NEUTRALISATION DEVICES

In parallel with the ongoing developments to underwater vehicles, industrial stakeholders have been working on **integrating different neutralisation devices for mine clearance applications.**

The **NATO charge** used by self-propelled drones is well-known for its efficiency. However, it is heavy – weighing around 125 kilos – and can only be deployed by heavier duty vehicles (weighing several hundred kilos).

Smaller charges, like the **Damdac charge**, have been developed, but to be effective they have to be placed even closer to the mine than the NATO charge. This is only possible with vehicles that are even stealthier than self-propelled drones, or with expendable vehicles.

The **compact design of shaped charges** makes them ideally suited to minekillers.

Underwater guns mounted on minekillers are competitive solutions versus shaped charges, but their length means they are more difficult to integrate in a minekiller than a shaped charge because of their size.

A CHALLENGING SCENARIO : PREPARATION FOR AMPHIBIOUS OPERATIONS

Most of mine countermeasures scenarios can be categorised according to three types :

- Harbour protection
- Shipping routes survey
- Support to amphibious operations

In the most demanding scenario : support to amphibious operations, mine identification and disposal tasks must be performed as two separate actions because of timing and stealth.

More specifically, **mine identification and disposal are now performed as two separate operations**, for reasons of time and stealth. Bearing in mind that the explosion of the first mine literally blows the cover of any mine clearance operations, **the time it takes to clear a coastal minefield must be short enough** (and ideally should occur simultaneously) to allow forces to disembark safely.

The minefield clearance phase has to be performed effectively if explosive charges have been placed near or on mines detected during the identification phase.

The support vessel remains offshore for obvious reasons, while the ROVs – which can be stealth or non-stealth vehicles – carry out these operations using NATO-type charges.

The use of autonomous USVs equipped with minekillers tethered to the USV by means of a cable and guided into a stationary position alongside each mine, awaiting the order to fire, **becomes less realistic the greater the number of mines**. This is particularly evident when clearing a minefield in the presence of strong currents.



For mines detected in shallow water, the destruction phase can be implemented by special forces frogmen entering the minefield by a **swimmer delivery vehicle (SDV)**. The divers can place explosive charges near the mines, equipped with firing mechanisms activated by an acoustic link.

However, this method is **unsuitable for mines located in areas where the currents are too strong for divers**. The same applies to deep-water mines unless the divers are sent down wearing special non-magnetic dry-suits or they are initially placed in decompression chambers.

For mines beyond the reach of divers (for physiological reasons), several concepts have been devised such as **autonomous minekillers** (e.g. the Franco-Norwegian VAMA project (2006–2009)) or **tagging** (laying a small explosive charge on, near or attached to a mine by a vehicle).

- **Autonomous minekillers appear to provide an effective way to destroy mines, but the absence of a wired link makes it difficult to confirm the relocation and identification of the mine to be destroyed.** Moreover, they will be expensive for a long time to come (unless they can be mass-produced) as they need to be equipped with navigation sensors and powerful data processing systems.
- **Tagging by drilling or nailing to the mine shell is also problematical as concerns discretion**, not just in terms of influence mines but also in terms of any mine equipped with accelerometers or acoustic sensors adapted to the drilling signature or the impact of the attachment system. In particular, discreet tagging of moored mines by a vehicle is a somewhat random operation which is probably incompatible with the scenario of preparing for landing.

Tagging by sticking a charge to the mine shell also raises the issue of discretion. It is unclear whether gluing in the marine environment has reached technology readiness, even if some shellfish have been able to crack this problem since time immemorial.

3. Implementation

THE SYSTEMS MENTIONED ABOVE HAVE DIFFERENT CHARACTERISTICS WHICH WILL HAVE AN IMPACT ON THE PLATFORMS FROM WHICH THEY WILL BE DEPLOYED.

PAP type vehicles are self-propelled, requiring only a small energy source to recharge the batteries, but they are bulky and weigh several hundred kilos, so they require handling equipment and a specially-adapted ship.

These heavy vehicles are nonetheless tolerant of steering errors and perform well in difficult environmental conditions.

Minekillers are also self-propelled and do not need a significant energy source. In addition, they are compact and lightweight and are therefore easy to integrate on small platforms. They are, however, more sensitive to the environmental conditions and less tolerant of steering errors.

Traditional ROVs, conversely, have the advantage of theoretically having unlimited endurance in comparison with PAP type vehicles or minekillers, but their use is restricted in currents by the umbilical cable.

They also have a significant impact on the platform from which they are deployed. A significant energy source is needed to power the system, and the umbilical cable with a diameter of around 15 mm and a length of several hundred meters also needs to be stored on a winch onboard the ship.

4. The future

MARITIME MINE CLEARANCE HAS CONVENTIONALLY BEEN CONDUCTED SINCE THE 1970S BY DEDICATED SHIPS CALLED MINEHUNTERS.

Mines are detected and classified using mine-hunting sonar systems installed under the ship's hull and by operators onboard the ship who analyse these images.

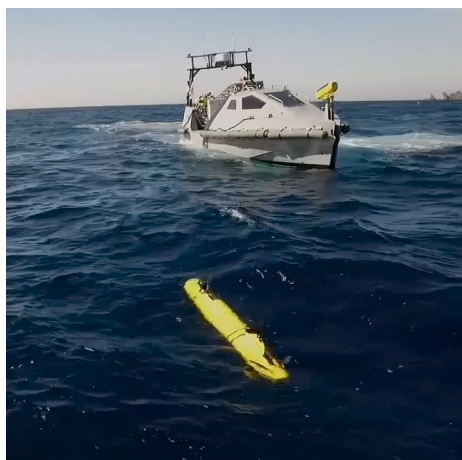
When detected objects are likely to be mines, a mine identification and neutralisation vehicle, such as a PAP or minekiller, is deployed to identify and neutralise the mine.

The cost of these ships can be astronomically high as they need to be able to enter minefields and detect mines without being detected by the mine, which would trigger its explosion.

Were any mines to explode, the ships also need to be able to withstand or at least survive such a blast. As a result, operations conducted by these conventional methods are very slow.

NEW METHODS ARE NOW AVAILABLE WHICH USE NAVAL ROBOTS.

These robots can be autonomous underwater vehicles (AUV)⁶ or unmanned surface vehicles (USV)⁷.



⁶ For example Exail's AUVs A9, A18 and A27

⁷ For example Exail's USV INSPECTOR

They are remotely deployed in the minefield by specialist vessels or from land.

In order to detect and classify mines, they carry or tow acoustic sensors.

In order to identify and neutralise mines, these seagoing robots (especially USVs) deploy other robots that are remotely controlled from the support vessel or from land.

One example is the Unmanned Maritime Integrated System (UMIS) developed by the Exail.

In order to identify and neutralise mines, UMIS uses a USV (INSPECTOR), first deploying an inspection vehicle (SEASCAN or K-STER I) and then a combat minekiller (K-STER C) to neutralise the mine.

The whole operation is supervised by an operator located onboard a ship far from the danger zone or on land. In this configuration, the minekillers are remotely guided by a radio link from the ship to the USV, then a wired (fiber optic) link between the USV and the inspection or combat minekiller.



Exail's UMIS Unmanned Maritime Integrated System

5. Conclusion

NO ONE SYSTEM ALONE IS ABLE TO MEET ALL OF THE REQUIREMENTS FOR NEUTRALISING A THREAT. DIFFERENT TYPES OF SYSTEM CAN BE USED COMPLEMENTARILY :

- **Traditional ROVs are useful for identifying and neutralising remnant ammunition and bombs (ordnance).** These peacetime operations benefit from being performed by ROVs as they reduce the risk for divers; they have to be performed when the current is weak owing to the very high impact of the umbilical cable on the hydrodynamic behaviour of the ROV system.
- **Conversely, as soon as the current is strong or the object is too deep underwater, self-propelled vehicles are the first choice.** Dominating a conflict where the place and the time for a mine-clearing operation are not, by definition, predictable thus requires using vehicles such as the K-STER or SEASCAN vehicle with no cumbersome umbilical cable.