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Arrangement and Stowage of AUVs on Military Mother Submarines

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ABSTRACT

One of the key features of the next-generation (sixth-generation) military submarines is their capability to carry, launch, and recover AUVs (Autonomous Underwater Vehicles). These AUVs will be responsible for defending the submarine, monitoring and listening to the surrounding environment. This is crucial because, in the future, AUVs are expected to pose the most significant threat to submarines. Heavy and few torpedoes are not effective for dealing with small and numerous AUVs. Therefore, the internal layout of future military submarines should be modified to enable the widespread use of AUVs. The two significant distinctions between AUVs and torpedo launchers are that, firstly, AUVs must be recoverable and not disposable, and secondly, AUVs must be deployed in large numbers simultaneously. As a result, their launchers will be different. In this article, 13 methods are proposed for the deployment of AUVs, and the advantages and disadvantages of each method are also listed. Also, due to the requirement for special launchers for AUVs, the sixth-generation submarines will feature double-hull or combined hull designs, whereas most military submarines in this century have been predominantly single-hull. The article also examines the issue of "ocean transparency," which poses the greatest threat to future submarines.

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1. Introduction

The study of the 120-year evolution of submarines reveals significant changes in their design, driven by technological advancements. If the submarine does not meet the requirements of the scientific and technological world, it cannot be effective. One of the major technological developments is the advancement of unmanned underwater vehicles (UUV) and AUVs (Autonomous Underwater Vehicles) for military purposes, including their deployment from large military submarines (referred to as mother submarines).

UUVs and AUVs present various advantages for naval operators, offering a means to minimize operational risks faced by service personnel while enhancing capabilities for tasks such as Intelligence, Surveillance, and Reconnaissance. The successful incorporation of UUVs into upcoming naval vessels is crucial for establishing an affordable and flexible capability for future navies. Integration of UUVs into a submarine's combat system poses a specific challenge, requiring the determination of the optimal quantity and combination of UUVs for a given mission. [13] investigated a novel method for exploring unconventional SSH(N) concepts within the design solution space. The significance of integrating UUVs into submarine design was assessed through an Operational Analysis (OA) that determines the mix of UUVs required to support various scenarios. (see also)[13].

Therefore, these unmanned devices, which will be a crucial part of future submarine developments, can serve two important functions and play two main roles in the host submarine: 1) As a detection and communication tool: AUVs, by deploying and leaving the submarine, can provide better and more accurate identification of the surrounding environment at a longer range. The sonar and listening equipment on submarines, which have been in use for 100 years, are weaker than AUVs for two reasons: 1) Because they are connected to the body of the submarine, sonar is unable to move away from it. Therefore, a submarine could not cover a greater distance. 2) Connecting to the hull of a submarine would be affected by internal noise (the submarine's self-noise), and the greater the sources of internal noise, the weaker the efficiency of sonar and detection equipment, especially in nuclear submarines. This is because AUVs are less affected by internal noise when they move away from the body. This way, the mother submarine will have improved environmental monitoring. In a more exceptional performance, these devices can utilize active sonar with fewer considerations and risks, significantly increasing its tracking range and accuracy. Large manned submarines use less active sonar because of the concern about being tracked. Additionally, AUVs facilitate communication without the submarine needing to surface or approach the water's surface for satellite communication or communication with surface vessels. This can be achieved with the assistance of AUVs [4] The main challenge in completing this task is the AUV's requirement for a substantial electrical power source to supply energy for sonar and communication devices. 2) As weapons: AUVs can act as effective weapons and carry out operations in a networked manner. Despite their small dimensions, they can pose significant threats to large submarines in an offensive role, or defend a submarine against attacking devices in a defensive role. For example, the dimensions and weight of torpedoes have remained almost constant over the last 70 years, serving as both an offensive device against submarines and a defensive device for submarines. The design of submarines has also been shaped and evolved based on these patterns, so much so that approximately 30% of the space inside SSK submarines is dedicated to storing and utilizing a handful of torpedoes.

Combining AUVs with a mother vessel is not limited to submarine hostile vessels[20]. integrated AUVs with an unmanned surface vessel for mapping the southern Ionian Sea. On the other side, the development of technology has affected the design and layout of submarines. For example, it is critical to consider the unintended impact technology can have on human operators, particularly regarding information flow and interactions within teams. [16]. proposed a novel circular configuration of the submarine control room. A practical design approach for submarine subsystems using a model-based systems engineering (MBSE) methodology was developed by Pearce and Friedenthal [12]. At the core of their approach is a system model that provides a precise, consistent, traceable, and integrated description of the submarine subsystem architecture. Developing intricate layouts for warships is essential for evaluating technical viability and aligning performance with emerging requirements in the initial stages of design. However, generating detailed and feasible layouts is a challenging and time-intensive endeavor. A mathematical tool, known as the WARship GEneral ARrangement (WARGEAR), was created by le Poole [5]. to aid naval architects in rapidly detailing ship arrangements at the space level.

Today, it is evident that highly advanced military AUVs with exceptional tracking capabilities, significant explosive power, and a range of several hundred kilometers (far surpassing the 20-kilometer range of torpedoes) are readily accessible. Furthermore, these technological advancements have rendered the use of a few 533 mm torpedoes ineffective against the threat posed by a large number of small attacking devices, as they occupy a significant volume and space inside the submarine, thereby increasing its tonnage. It is illogical to use a 6-7 meter torpedo weighing about 1800 kg to counter a 100 kg attacking AUV. If the number of these attacking objects reaches 10 or 20 at once, the outcome is clear. The submarine is unable to fire a large number of torpedoes simultaneously due to limitations in the static stability and volume of the tanks, as well as restrictions on water intake. Hence, it is evident that future submarines must be equipped with smaller, lighter weapons and enhanced capability to fire simultaneously in order to address future threats. In this way, it can be ensured that the next generation of submarines, which will include various types of AUVs as part of the mother submarine, will have enhanced operational and offensive capabilities and will be secure against external threats. This article is a step towards understanding one of the important features of future submarines [11].

2.Unmanned Vehicles; The main threat against submarines

A review of the world's scientific and news sources reveals that the majority of anti-submarine warfare (ASW) technologies have been developed in the last decade for installation on Un-Manned vehicles (UMV). UMVs have three main branches: UAVs (unmanned aerial vehicles), USVs (unmanned surface vehicles) and UUVs (unmanned underwater vehicles). The main advantage of UMVs has been the following three factors: low cost, the possibility of production and application in large numbers, no human casualties in case of destruction (which causes more courage in their use for identifying submarines [1].In fact, the main reason submarines to remain hidden for the past 100 years, has been the very heavy costs of ASW operations, which were mainly carried out by airplanes, helicopters, and ships. The UMVs solved this great limitation to a surprising extent [7].

3.Existing solutions for submarines to prevent extinction

With the current situation in the development of ASW technology and equipment to transparent the oceans, the biggest and most expensive and crewed military submarines in the next decade will courage the most damage and will be most at risk [8]. Therefore, the following main approaches can be a solution to prevent premature extinction of manned submarines: 1) Reducing the dimensions and tonnage, which can be followed by reducing the number of crews and also using compact and small nuclear reactors. Reducing the weight by reducing the number of crew, in addition to the weight of each eliminated crew, means reducing the weight of food, fresh water, water desalination facilities and storage tanks, purification facilities and ventilation of the interior space and sleeping equipment and sanitary space. In addition to weight reduction, there will be a great reduction in the required volume of the internal space of the hull, which includes the reduction of the sleeping space and the reduction of the support spaces for human life. Almost half of the space of nuclear submarines is dedicated to the propulsion system, which can be greatly reduced by reducing energy consumption and the number of crews and new technologies in the construction of compact reactors. 2) Reducing the crew, in addition to the above, will mean reducing human casualties in the event of the destruction of a submarine. 3) Cost reduction, which includes the above two items. 4) Wide use of UMVs as offensive and defensive weapons for manned naval submarines. In this way, the strategy of "a large number of prey against a large number of predators" can be followed to keep the submarine itself healthy [6]

4.Future submarines; Single hull or double hull

The study of western and Eastern submarines shows that submarines in this century have been intended towards single hull architecture. Even the new designs of Russian submarines, such as the Amur class submarine, are designed with a single hull, while the Russians have traditionally been intended to double hull submarines. Analysing the presented concepts of future submarines all show that future submarines will be double hull or hybrid hull submarines. The main reason for this was the ability to use a large number of UMVs and light torpedoes and light missiles outside the pressure hull. In hybrid hulls, a part of the body is double hull and the rest of the body is single hull. Previously, hybrid hulls were used to accommodate middle ballast tanks and quick dive tanks. Fig. 1 shows an example of the design of future submarines.

Fig 1. A double hull future submarine, Capable of carrying a large number of AUVs [17]

5.Oceans Transparency

Nowadays, the ocean transparency and the easy detection of submarines using modern equipment may forever negate the existence of nuclear-powered and long-range submarines. Until now, the oceans have served as a sanctuary for the nuclear-powered submarines attacks. In fact, by possessing an unlimited range and the ability to stay several hundreds of nautical miles away from the perilous coastal waters of countries, they ensconced in the depths of the oceans. Firstly, this always placed them in a secure and covert environment, making it challenging to access and aggress against them. Secondly, they ensured a secondstrike (nuclear attack) capability following the enemy's initial nuclear attack. This, in turn, was instrumental in causing nuclear deterrence. However, conditions change rapidly, and with the increasing variety, precision, and significant scope of submarine tracking equipment, even the depths of the oceans have become transparent to nuclear submarines, making them insecure. This article scrutinizes the subject by analyzing the most recent scientific and technical achievements and examining the perspectives of military experts worldwide based on available sources. The advancement of key technologies, including 6G technology in information exchange, artificial intelligence (AI), precise sensors, high-energy-density batteries, and the integration of these innovations into unmanned platforms, will likely lead to the gradual replacement of nuclear-powered submarines in the military within the next two to three decades. Countries are increasingly transitioning to mobile platforms or hidden underground silos for launching nuclear missiles instead of submarines. The significance of this lies in the intelligent targeting of future defense investments on a global scale. Figure 2 illustrates the enhanced submarine tracking capabilities using UMVs and other modern ASW equipment.

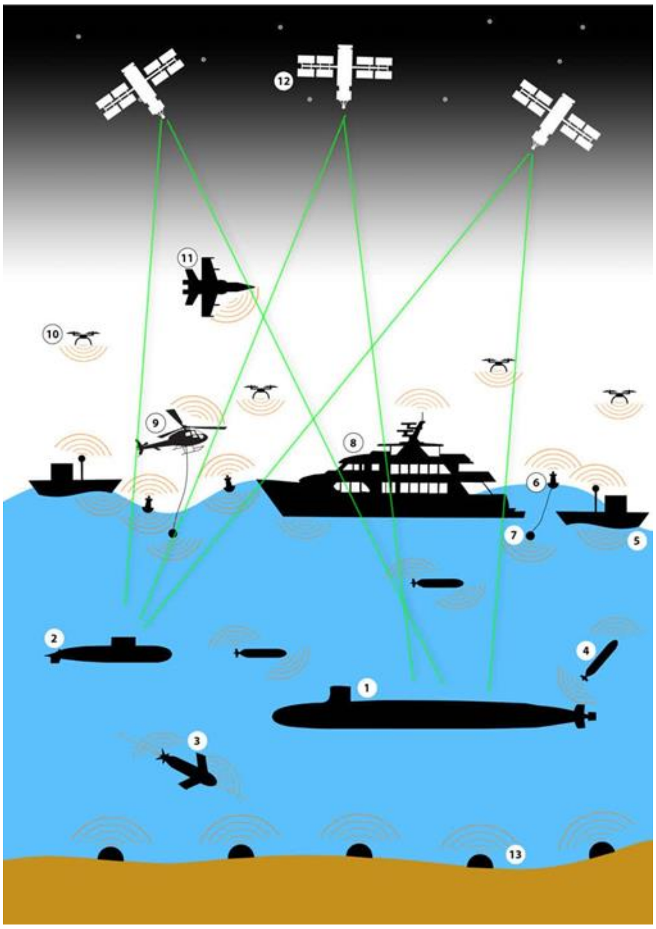


Fig 2. The concept of ocean transparency by modern ASW equipments and UMVs

1	SSBN
2	SSK
3	Underwater Glider
4	AUV
5	ASV
6	Sonobuoy
7	Active/Passive submersible sonar
8	ASW Ship
9	ASW Helicopter
10	UAV
11	ASW Aircraft
12	Satellite
13	Seabed hydrophone

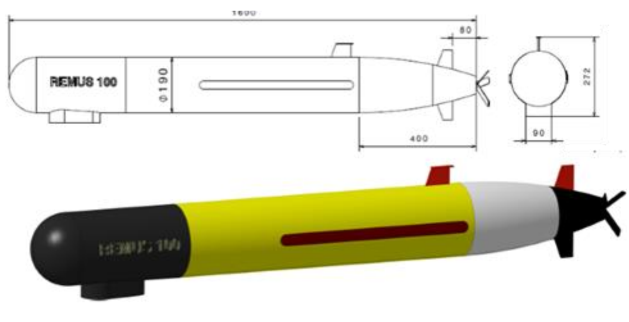
6. Selected AUVs

The specifications of some of AUVs that are available in the world have been selected (Table 1) and their placement on the mother submarine has been investigated. The purpose of choosing different plans is to investigate the possibility of small, medium and large submarines on the mother submarine. The 3D drawings of AUVs are prepared in Fig 3.

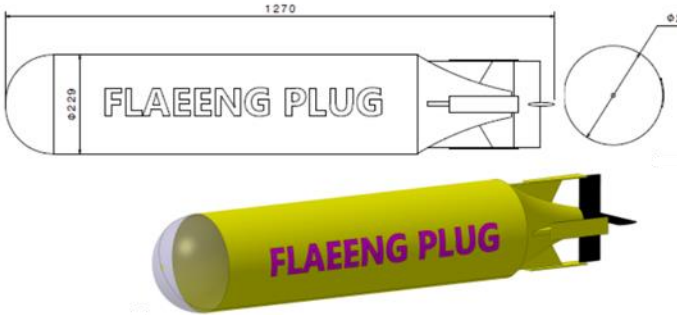
Table 1: Specifications of selected AUVs

Name	Length (m)	Diameter (m)	Mass (kg)
Remus100	1.6	0.19	37
Flying Plug	1.27	0.23	45
Remus6000	3.25	0.32	240
Bluefin21	2.4	0.53	180
Bluefin21-BPAUV	3.3	0.53	363
Hugin	5.35	1	1400
AUSS	5.5	0.79	1273
Seahorse	8.7	0.96	4536
Theseus	10.8	1.3	8845
Spray Glider	2	0.2	51

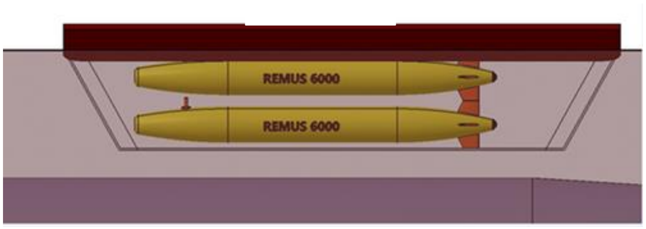
(a)



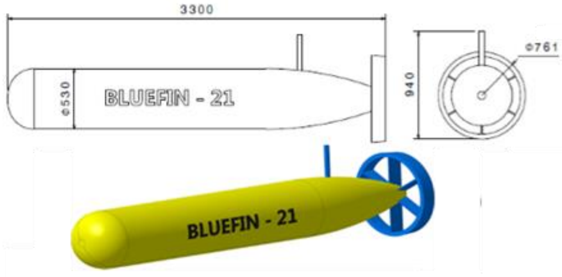
(b)


1270
Φ229
FLAEENG PLUG
FLAEENG PLUG

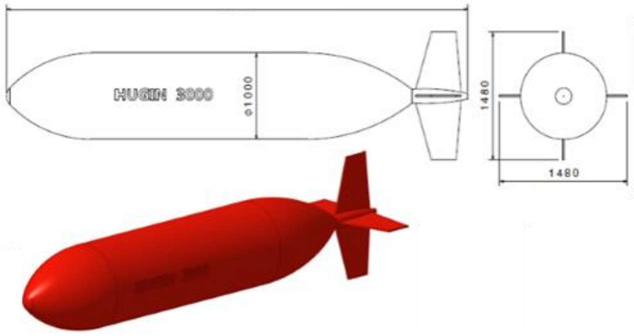
(c)


REMUS 6000
REMUS 6000

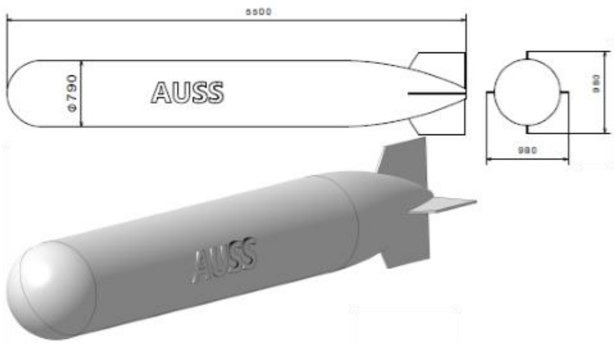
(d)


3300
Φ530
BLUEFIN - 21
940
Φ761
BLUEFIN - 21

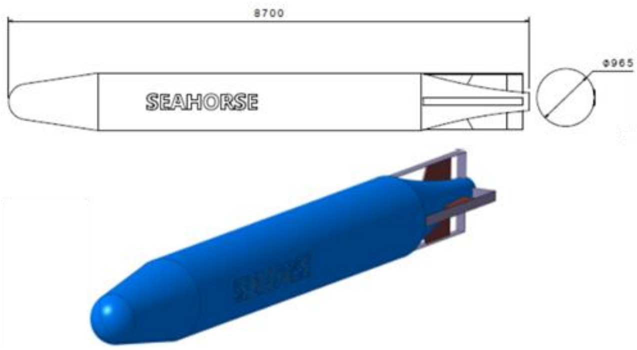
(e)


HUGIN 3000
Φ1000
1480
1480

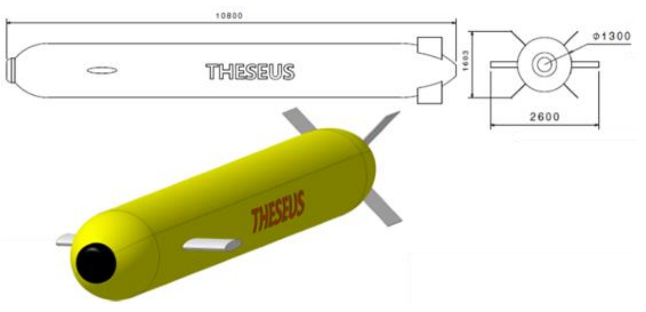
(f)


Φ790
AUSS
AUSS

(g)


8700
SEAHORSE
Φ965

(h)



(i)

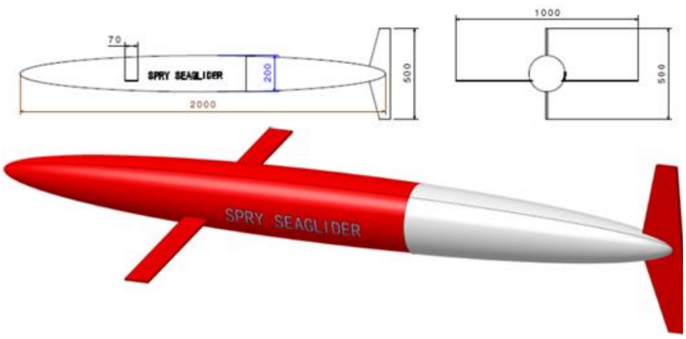


Fig 3. Specifications of selected AUVs
(a): Remus100 , (b): Flying Plug
(c): Remus 6000 , (d): Bluefin 21
(e): Hugin3000 , (f): AUSS
(g): Seahorse , (h): Theeeus , (i): Spray Glider

7.Specificationd Of Mother Submarine

For arranging the AUVs on a mother submarine, a Russian 2300-ton submarine (Kilo class) has been considered (according to the drawings in Fig. 4) [3]. It should be noted that this submarine is considered only as a sample to make a comparison between the dimensions of the submarine and AUVs. This submarine is a double hull diesel-electric submarine.

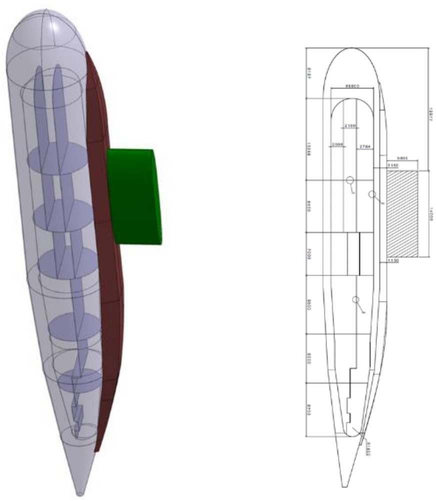


Fig 4. Specificationd of Mother Submarine

8. The architectures on the submarine

In this part, 13 different architectural designs of AUVs on the mother submarine have been investigated and related 3D drawings have been presented. The advantages and disadvantages of each of them are also listed. Also, if there is a similar example in the world for each design, they are also mentioned.

8.1.Design 1: The Lock behind the Sailing

In this design, a cylindrical pressure tank (lock) with a diameter of 2.3 meters and a length of 8.7 meters is placed behind the sailing, and a vertical nozzle connects the space inside the lock with the space inside the submarine. To reduce the hydrodynamic resistance, a cover is drawn on this tank in such a way as to minimize the hydrodynamic resistance. The possibility of the crew moving between the submarine and the lock in a dry environment creates this great advantage that the personnel can prepare for them, moments before leaving AUVs [17]. Also, when leaving AUV, one or two divers can monitor their departure and return process. To exit AUVs, the hatch door of the vertical nozzle is closed and the space inside the lock is flooded from the water inside the compensation tanks. After complete flooding of the space inside the lock and pressurization with the external environment, it is possible to open the main door of the tank. The volume of the space inside this tank is equal to 36 cubic meters, in such a way that in addition to AUVs of different dimensions and tonnage, wet submarines and diver carrying chariots can also be used. According to the arrangements in Figs 5 to 8, there is a possibility of locating of two Chariot. It is also possible to carry 90 small AUV such as REMUS100 to carry out extensive (but short-range) offensive operations or one large AUV. It is possible to install two HUGIN3000 model AUVs with a length of 5.3 meters and a body diameter of 1 meter and a maximum width and height of 1.5 meters for longer ranges and longer duration. In this way, a wide range of AUVs can be used in such a design [1].

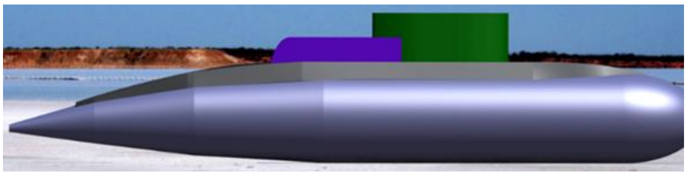
Advantages of Design 1: The most important advantages of this architecture can be listed below:

- Possibility of combined use for carrying small and large AUVs and wet submarines.
- It is possible to use it as a diver exit trunk for simultaneous exit of a large number of divers and chariots in complete safety.
- The possibility of carrying a large number of small suicide drones.
- The possibility of easy exit and easy and safe recovery of AUVs. One of the big problems of using AUVs is their return after operations and their recovery. In this place, due to the large diameter of the lock and the good

maneuverability of the AUVs, it is possible to recover them easily, quickly and safely. Also, for operations at shallow depths, it is possible to deploy a diver inside the lock to monitor and guide the AUVs (due to their zero wet weight) for intering and seating on bed.

- It is possible to completely separate this lock from submarine when it is not needed.
- The vertical nozzle connecting the inside of the lock and the submarine, can be used as a AUVs and diver's exit trunk.
- The possibility of being used as a crew dormitory by placing temporary bunks. Submarines usually face a shortage of bunks for the crew to rest, and there is not one bed for each crew [2].
-

Fig 5. The lock behind the Sailing of Ohio class submarine (Bell, 2000)



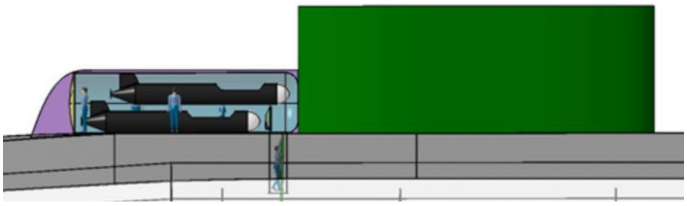


Fig 6. Arranging 2 Chariot inside the lock

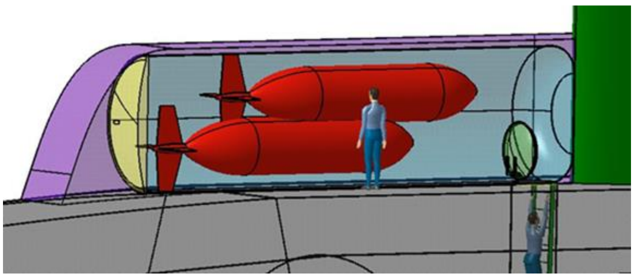


Fig 7. Arranging 2 HUGIN3000 inside the lock

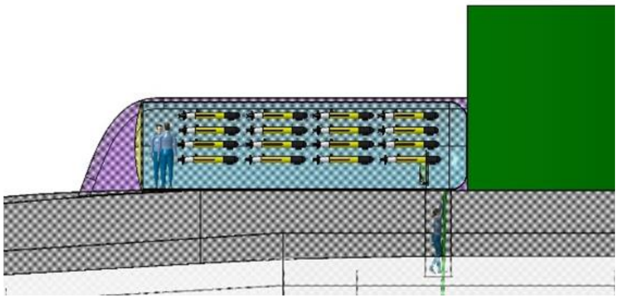


Fig 8. Arranging 90 REMUS100 inside the lock

8.2.Design 2: Aquarium inside pressure hull

This design is derived from the Texas submarine (SSN-775) in such a way that a part of the space inside the pressure hull is transformed into a separate tank by two adjacent pressure bulkheads at a distance of 1.2 meters, which is called "aquarium". This means that many types of AUVs can be used inside it. This space has a

volume of about 13 cubic meters, an average height of 2.5 meters and a maximum width of 3.4 meters. In the space inside this tank (aquarium), a very large number of AUVs and divers carrier (chariot) can be place. As shown in Fig. 9, for example, there are at least 10 divers and 10 Remus 100 in the space of this aquarium. Also, by using the flexible cover, the air can be kept trapped in the upper part of this tank so that the diver's head remains in a dry environment and it is easier to establish communication and direct vision. Also, above this space, there is a cylinder for exiting from the pressure hull, which has a diameter of 80 cm and a height of 2.3 meters, in which at least one diver with diving equipment can be placed. To flooding the aquarium, the water inside the compensation tank should be used [1].

Advantages of Design 2: The most important advantages of this architecture can be listed below:

- It is possible to use a combination of AUVs and divers simultaneously. In this design, small and medium-sized AUVs can be carried by divers. Because the AUVs have "zero wet weight" in the space inside the water and can be easily moved and transferred outside by the crew and vice versa.
- The possibility of carrying a large number of small suicide AUVs to deal with group attacking.
- The possibility of using it as a diver exit trunk to exit a large number of divers simultaneously, completely, safely and quickly.
- The vertical nozzle connecting the space inside the aquarium to the outside of the submarine can be used alone for the exit of a diver or AUVs .

- The possibility of using it as a rescue tank or compartment for the crew during accidents.

One of the disadvantages of this plan is that it is not easy to recover the drones after the operation and return them to the body. Also, a part of the useful space inside the submarine pressure hull should be allocated for this purpose. Also, the structural weight of the pressure hull should be increased due to the one addition pressure bulkhead (in the form of a circular section) to withstand the pressure of at least 60 meters of water depth (for 6 bar operarional pressure and 8 bar design pressure). Also, in this case, AUVs cannot leave without the intervention of the crews (divers). For this reason, it is not possible to leave a large number of them in a short period of time [18].

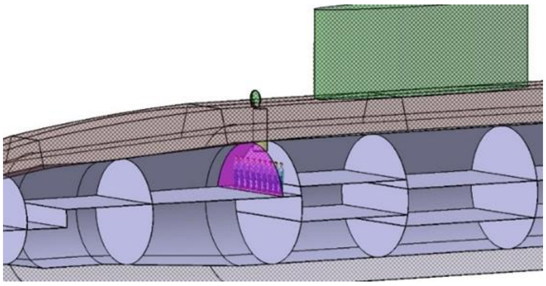


Fig 9. Showing the position of the aquarium among the submarine compartments

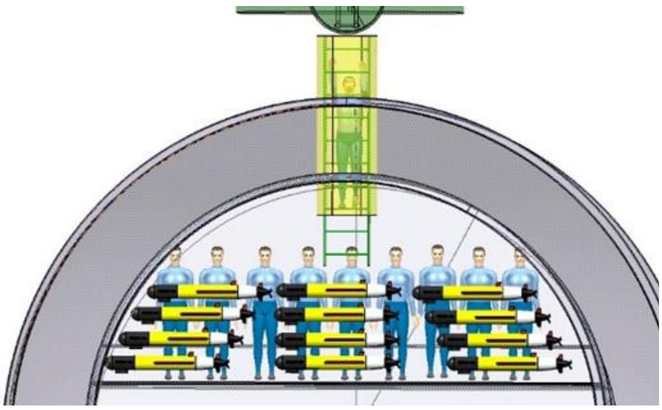


Fig 10. Showing the cross section of the aquarium with 9 divers and 12 REMUS100 AUVs. Connection Nozzle at the top of the aquarium

8.3.Design 3: Conical Exit Trunk

This design is derived from the design implemented according to Fig11, which uses the exit trunk on the main hatch of the submarine as the AUVs and diver's exit tank. In this design, instead of using a common cylindrical tank in submarines, a tank with a trapezoidal cross-section and conical shape is used.

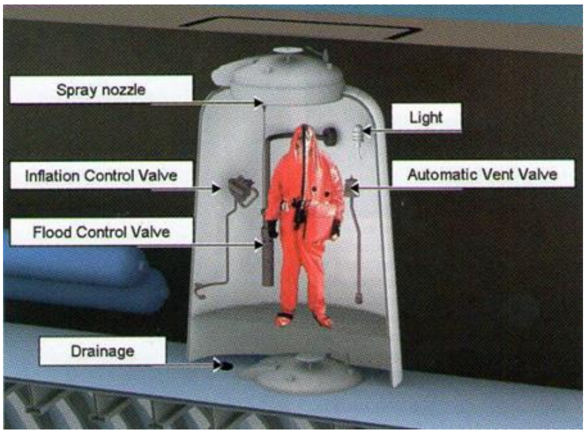


Fig 11. Trapezoidal cross-section and conical shape exit trunk [14]

According to the dimensions of the sailing, the trapezoidal cross-section and its height can be considered in such a way that a larger number of divers and drones can be accommodated in it. In Fig12, small dimensions are considered for this trunk, which can accommodate at least 4 divers inside. Also, a diver can be placed inside it with a large number of small or a limited number of medium sized AUVs. The total space inside this tank is equal to 4.4 cubic meters, which must be filled with water from the compensation tanks for the diver and AUVs to exit, and the outstand main door should be opened after pressure equalization.

Advantages of Design 3: The most important advantages of this architecture can be listed below:

- Not occupying the space inside the pressure hull and using the space inside the sailing.
- It is possible to use a combination of AUVs and divers simultaneously.
- The possibility of carrying a large number of small suicide AUVs to deal with group attacking.
- The possibility of using it as a diver exit trunk to exit a large number of divers simultaneously.
- The possibility of using it as a rescue tank for the crew during accidents.

One of the disadvantages of this design is that it is not possible for divers and AUVs to leave the space inside the sailing easily, because after leaving the trunk, they have to leave the space inside the sailing as well, which is not an easy task in the dark and vague underwater space. Of course, if the upper door of the tank is opened close to the upper parts of the sailing, it is possible to exit more easily [19].

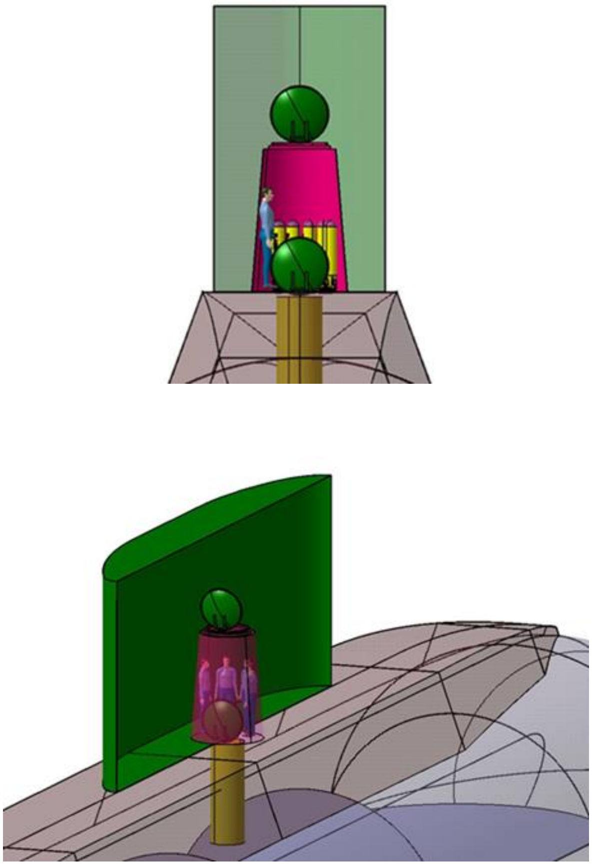


Fig 12. Conical trunk inside the sailing as the main passage and the exit trunk of the divers and AUVs

8,4.Design 4: Dock behind the sailing

This design is taken from the Fig. 13 related to the Russian Belgorod submarine, in such a way that it has been tried to use the space inside the deck and the outer hull to place and sit the AUVs. In Latin sources, this space is called "Dock".

Fig 13. The dock on the upper deck of belgorod submarine.

In this very simple and practical design, a cube-shaped non-watertight tank with large door dimensions is placed behind the sailing. The large non-watertight doors on this tank can be opened up to an angle of more than 90 degrees, so that it is possible for a large AUV to get out of the tank easily. Also, in this design, it is easily possible to recover the AUVs because the 120-degree angle of the opened doors leads the AUVs into the dock . This dock is immediately connected with the outside environment, and when the AUV returns, it does not need to pass through narrow passages or small cylinders to enter the dock, because the large dimensions of the doors in the open state with an angle of about 120 degrees easily embrace the AUV and they put it inside the tank. The considered dock according to Fig. 14 has a length of 4 meters, a width of 1.65 meters and a depth of 0.9 meters (which depth can extend to the pressure hull and reach 2.2 meters), which of course depends on the dimensions. The submarine, the height of the deck, the distance between the pressure hull and outer hull, the dimensions of this tank can be easily increased in such a way that it can accommodate relatively large AUVs inside. On the other hand, due to the fact that this tank is not a watertight tank, it does not need to be drained or flood.

Advantages of Design 4: The most important advantages of this architecture can be listed below:

- The possibility of exiting, returning and recovering the drone in the simplest possible way without the intervention of a diver.
- The possibility of simultaneous and mass exit of a large number of AUVs due to the proximity to the open space outside.
- Numerous and extensive choices for the dimensions and tonnage of the AUVs due to the non-watertightness of the tank.

The dimensions considered in Figs 15 and 16 have the capacity of about 30 Remus100 or 4 Remus6000. The main problem of this design is that the AUVs are placed in a non-watertight environment and it is difficult to access them, and it is only suitable for fully smart AUVs with pre-programmed capabilities [1].

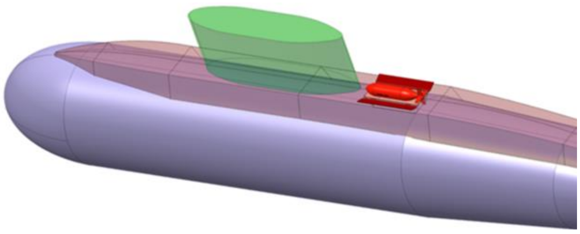


Fig 14. Placement of a HUGIN3000 in the dock

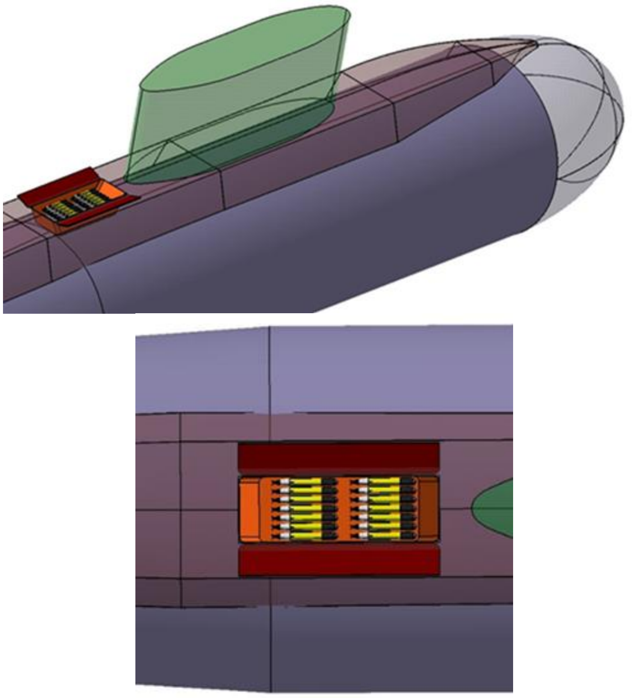


Fig 15. Placement of 28 REMUS100 inside the dock of design 4

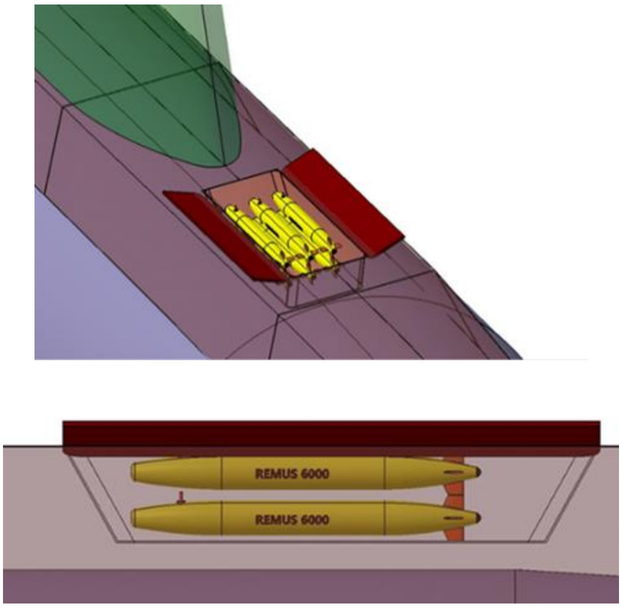


Fig 16. Placement of 6 REMUS6000 inside the dock

8.5.Bow horizontal large tube

The bow horizontal large tube has a diameter of 1.2 meters and a length of 8.6 meters. This tube is placed in the lowest part of the bow of the submarine. This design is given from the idea of BMT company as shown in Figs 17 and 18**.**

Fig 17. UUV launcher in BMT VIDAR-7

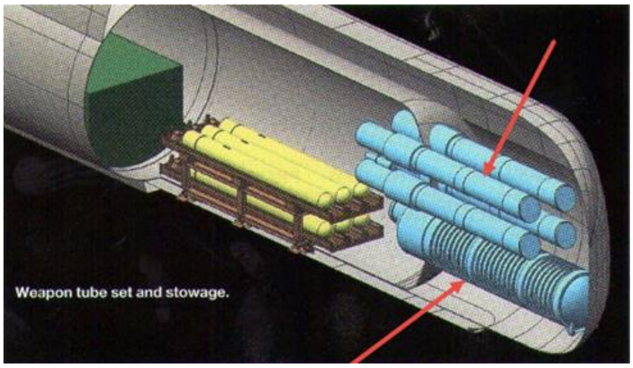


Fig 18. Bow horizontal large tube as a aquarium [14]

A large number of small and medium-sized AUVs and a suitable number of divers can be accommodated in its interior. It is also possible to use divers and AUVs for them in combination. The end of this tube opens inside the pressure hull, which makes it possible to access the AUVs easily. Also, divers will no longer have to get out of the torpedo tubes in emergency situations, but they can easily get out of this tube with a suitable diameter in a safer and faster way. The volume of this tube is equal to 9.7 cubic meters, in which, for example, about 50 Remus100 AUVs can be placed. Also, the number of at least 8 divers can be accommodated inside. An AUSS drone or a Seahorse can be placed inside it (Figs 19 to 24). To fill the inner space of the tank, the water inside the compensation tanks should be used.

Advantages of Design 5:The most important advantages of this architecture can be listed below:

- It is possible to use a combination of AUVs and divers simultaneously.
- The possibility of carrying a large number of small suicide AUVs to deal with group attacking.
- The possibility of using it as a diver exit trunk to exit a large number of divers simultaneously, completely, safely and quickly.
- The possibility of easy exit andeasy recovery of the tanks due to the large diameter of the tank in the submarine bow.
- The possibility of communication with the inside of the pressure hull until a few moments

before the exit of the AUVs and the possibility of checking the conditions of the AUVs in a dry environment.

- The possibility of using different types of missiles and torpedoes with different diameters for testing in the real environment of the sea.
- The possibility of using the water inside the torpedo compensation tanks (water specific to launching the torpedo) to launch from this large tube. Therefore, there is no need for separate water tank.
- The potential for use as a crew dormitory by placing temporary bunks [1].

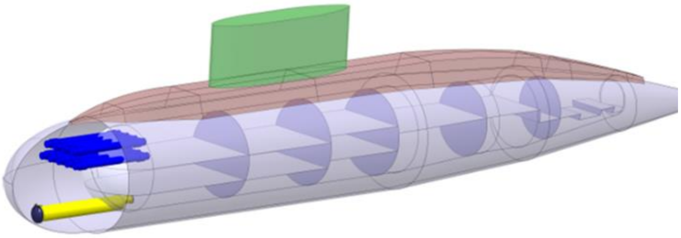


Fig 19. Situation of bow horizontal large tube

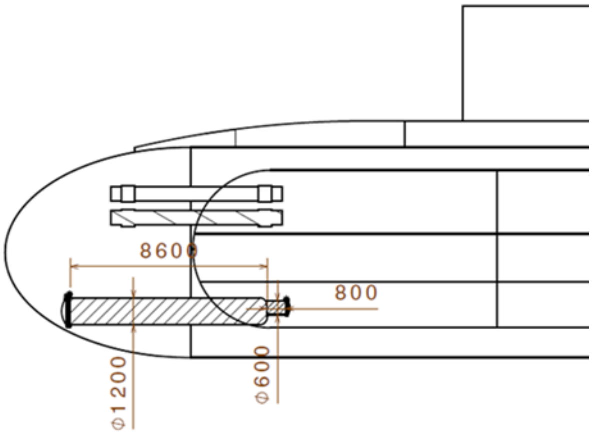


Fig 20. Dimensions of bow horizontal large tube

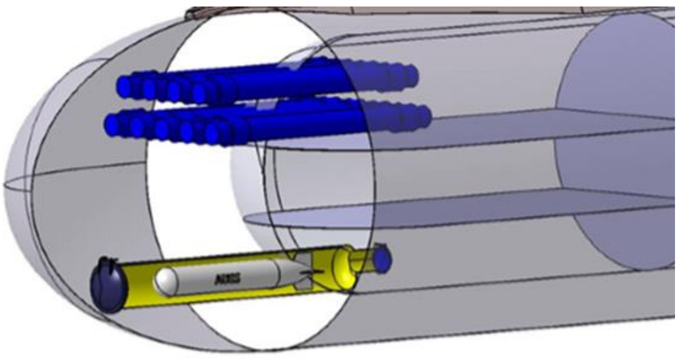


Fig 21. Position of AUSS in the bow horizontal large tube

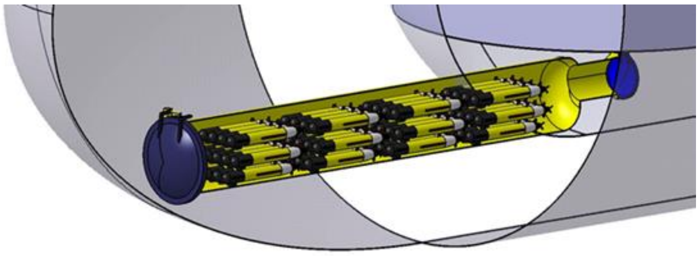


Fig 22. Position of 48 REMUS100 in the bow horizontal large tube

Fig 23. Position of SEAHORSE in the bow horizontal large tube

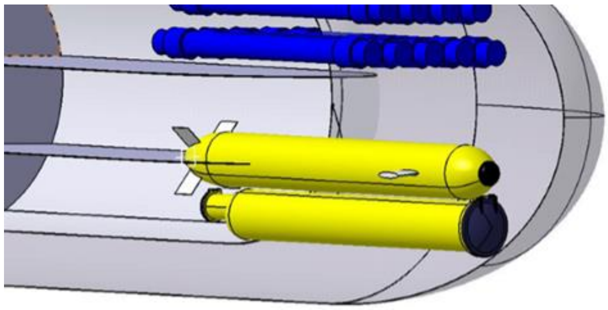


Fig 24. Comparison of dimensions of THESEUS with the bow horizontal large tube

8.6. Escape Trunk

This design is the same crew's escape tank (Escape Trunk) according to Figs 25 and 26. In such a way that if the submarine sinks, at least one third of the crew can sit inside it and attempt to release the tank to rise to the surface of the water. Therefore, if such a tank is installed in a submarine, it can easily be used as an aquarium for AUVs, and all the advantages mentioned in Design number 3 can be used here. Also, a suitable number of heavy AUVs and even underwater gliders can be placed inside it [19].

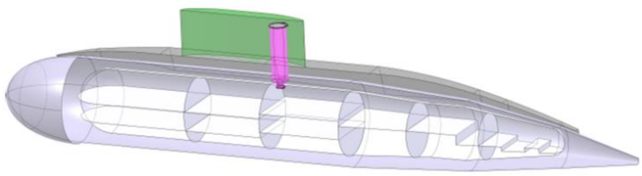


Fig 25. Location and comparison of the dimensions of the escape trunk compared to the submarine

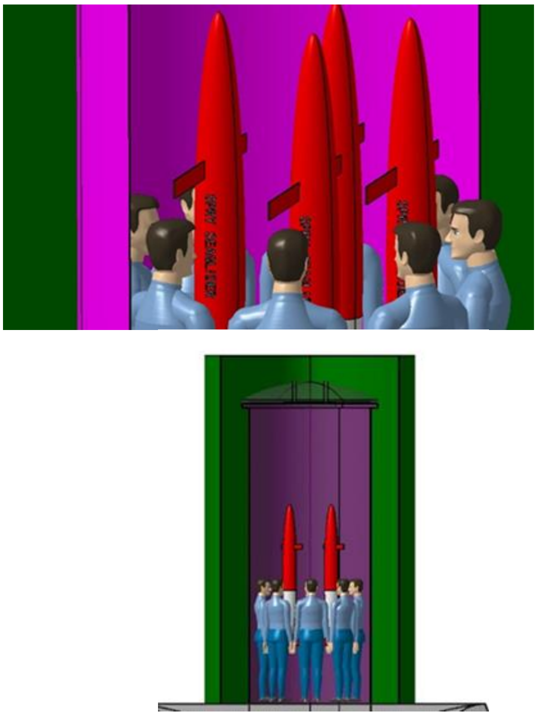


Fig 26. Location of 8 divers and 4 SEA GLIDER inside the trunk

8.7.Design 7: Cylindrical tank in the low part of the bow

This Design, which includes reducing the diameter of the pressure hull in the bow part, has already been presented in Figs 27 and 28. In fact, by reducing the diameter of the pressure hull, it is tried to use the large space created between the outer hull of the bow and the pressure hull to place all kinds of tanks for launching AUVs, missiles, torpedoes and divers exit. The idea of reducing the diameter of the bow pressure hull can be one of the successful models for the use of various types of AUVs in different dimensions and tonnage. One of the options created in this space, according to Figs 29 and 30, is a large cylindrical tank with a volume of about 19 cubic meters, length of 6 meters and diameter of 2 meters. One of the important uses of this tank can be the diver's exit tank because it has a hatch connecting with the space inside the submarine's pressure hull. There is also a vertical nozzle for exiting from the submarine. The dimensions of this tank are such that all kinds of AUVs can be placed in it according to the Figs 29 and 30. Also, the crew can have easy access to the AUVs in the dry environment and prepare them before launch. Also, the space of this tank can be used as a resting and sleeping space for the crew under normal conditions. In this way, the multi-purpose use of this tank has caused it to be considered as a new and practical design, even for future submarines. It should be noted that the exit of the AUVs and their recovery is done through a vertical hatch with the help of a diver. The space inside this tank is such that by trapping air in the upper part of the tank and making the tank half-full, it can be more convenient for divers' activities, both for diving activities and for exiting the AUVs. It is mentioned that the transport and movement of AUVs is easily possible by humans due to their zero wet weight inside the water [3].

Advantages of Design 7: The most important advantages of this architecture can be listed below:

- The possibility of multi-purpose use as a diver's exit trunk, a diver's depressurization room, medical hi-pressure oxygen room, an aquarium for AUVs and a crew's sleeping space and bunks.
- The possibility of placing a large number of small AUVs.
- The possibility of accessing the space inside the pressure hull and preparing the AUVs until moments before departure.
- The possibility of trapping air in the upper part of the tank and keeping the water in the half level to perform various activities while leaving.

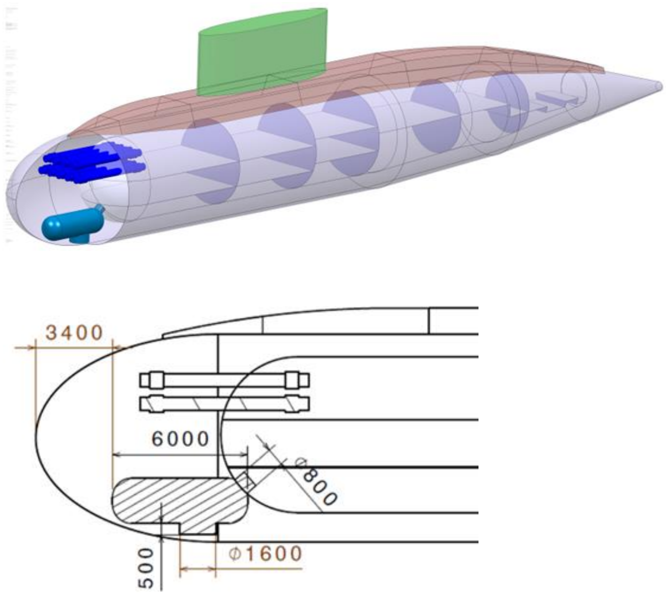


Fig 27. Comparison of the dimensions of the trunk compared to the submarine in the condition of -without reducing the bow pressure hull diameter

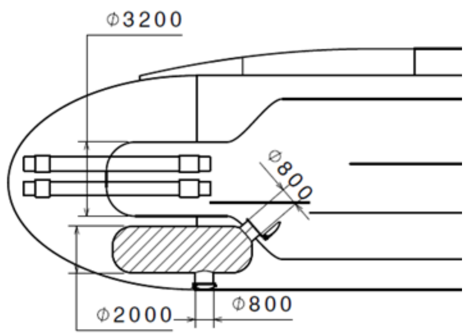


Fig 28. Comparison of the dimensions of the trunk compared to the submarine in the condition of - reduced bow diameter of pressure hull

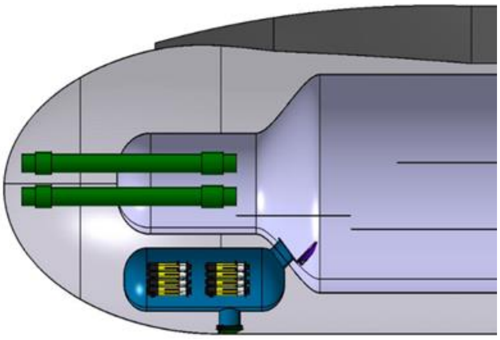


Fig 29. Placement of 32 REMUS100 inside the trunk

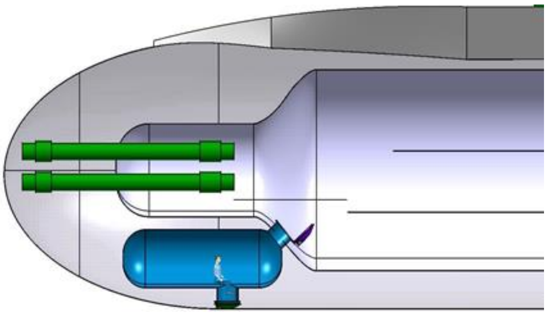


Fig 30. Comparison of the dimensions of a diver inside the trunk

Also, in the continuation of Design 7, other existing spaces resulting from the reduction of the pressure hull diameter can be used for similar designs of the above tank according to Figs 31 to 33. In this design, an inclined tube with a diameter of 1.2 meters and a length of 5.4 meters and a volume of about 6 cubic meters is placed at an angle of 10 degrees relative to the horizon line, in such a way that there is a short distance to the exit from the outer hull of the bow. In this design, a large number of AUVs of different sizes can be launched and recovered. Also, at least 4 crews can sleep inside it. Another use of this tube can be for easier loading of torpedoes [4].

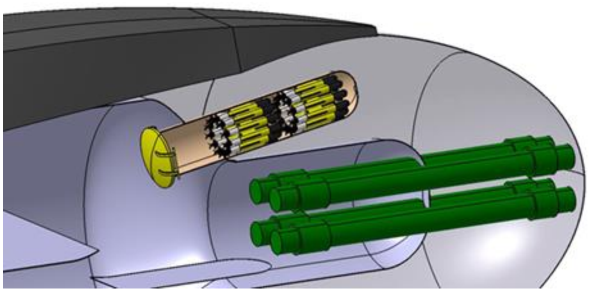
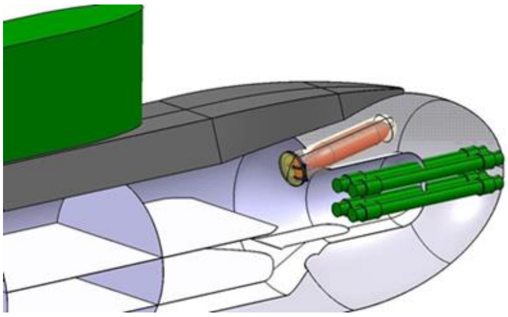


Fig 31. Placement of 22 REMUS100 inside the inclined tube



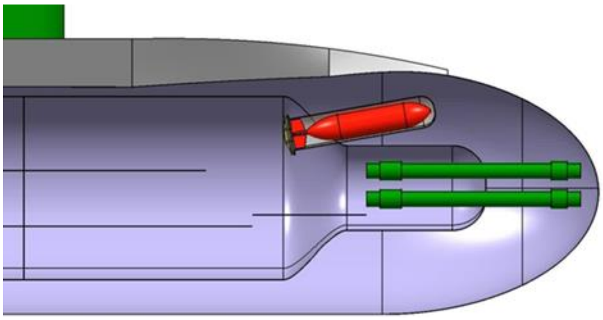


Fig 32. Placement of HUGIN3000 inside the inclined tube

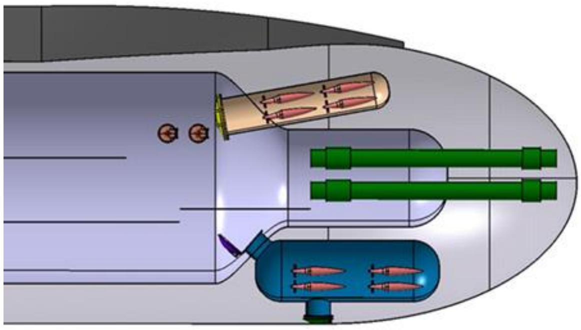


Fig 33. The combination of a cylindrical exit trunk and an inclined tube and two side tubes

Next stage in the Design 7 is some small bow launchers. This design also depends on reducing the diameter of the pressure hull in the bow area, where a number of small and medium size launchers of AUVs, missiles and torpedoes can be placed in two modes:

- For the case that the launchers are placed outside the pressure hull according to Fig. 34 and are not connected to the inside of the pressure hull.
- Designs that are inserted into the pressure hull (like the plans mentioned above). The bow position is an ideal place for placing small launchers, and reducing the diameter of the bow pressure hull creates an ideal position in this regard (Fig. 35)[6].

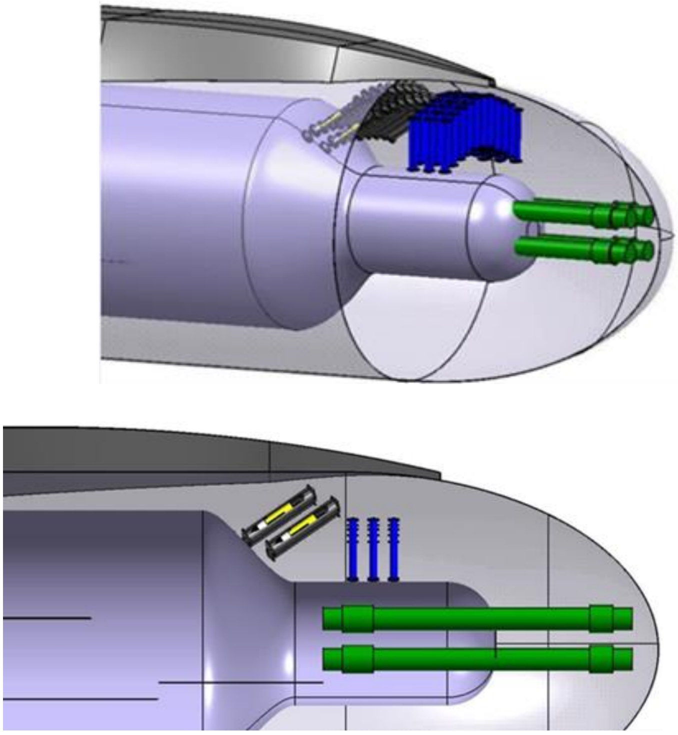


Fig 34. Arrangement of a number of external launchers (vertical and inclined)

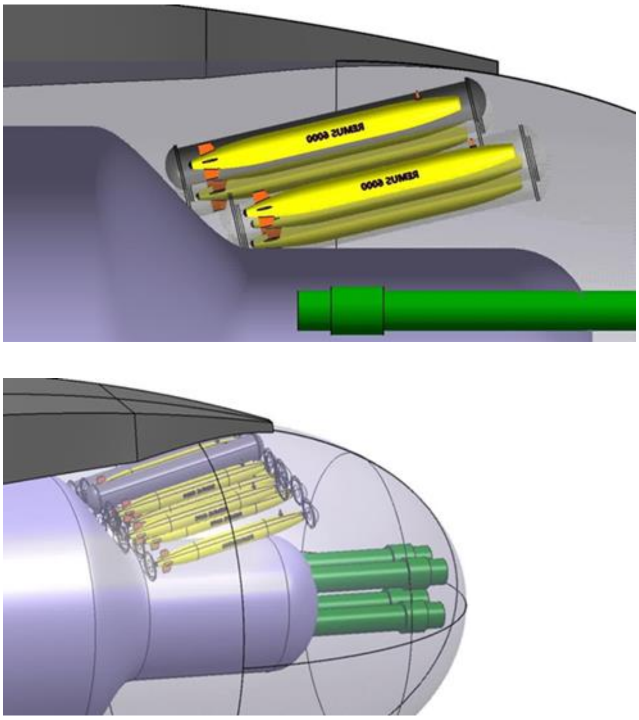


Fig 35. Arrangement of REMUS6000 inside the outer inclined launchers

8.8.Design 8: Bow Dock

In the continuation of plan 7 and similar to plan 4, in order to use the space created by reducing the diameter of the bow pressure hull, a non-watertight cubical tank, which is known as "dock" has been used for this purpose (Fig 36). The dimensions of this tank can be increased according to the tonnage of the submarine and the available space in the bow. In the current design, a tank with a length of 3.5 meters, a width of 3 meters and a depth of 2.5 meters has been used, with a volume of about 25 cubic meters, which can accommodate a large number of small and medium or small numbers of large AUVs. All advantages of the dock behind the sailing (Design 4) are also true here (Figs 37 and 38).

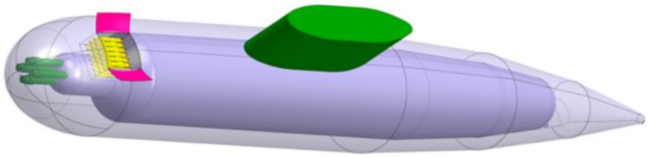


Fig 36. A view of the bow dock in comparison with the overall dimensions of the submarine

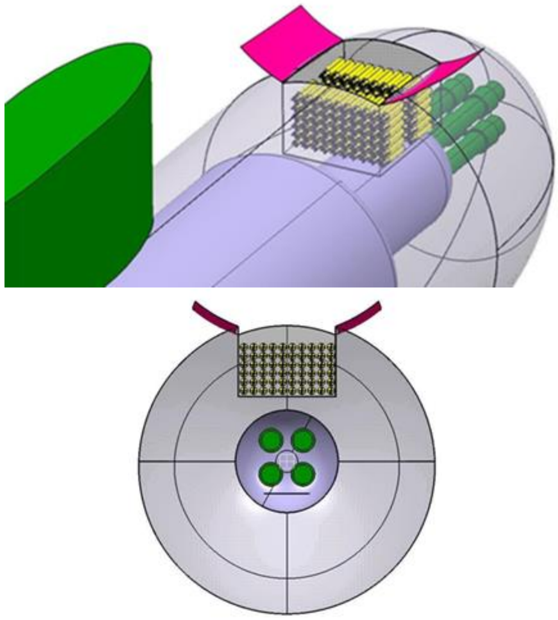
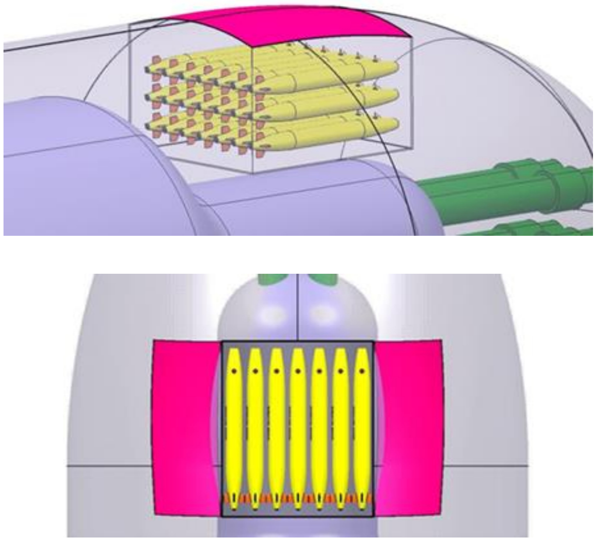


Fig 37. Arrangement of 60 REMUS100 inside the bow dock



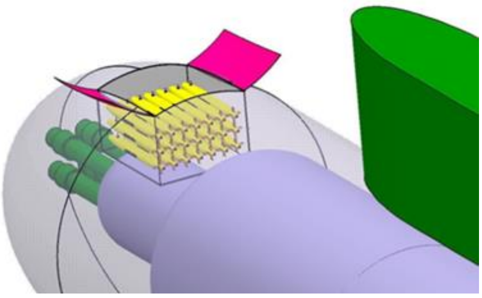


Fig 38. Arrangement of 21 REMUS6000 inside the bow dock

8.9.Design 9: Small side launchers

This design is very suitable for double-hull submarines. The side tubes can be used on the left and right side of the body to exit the AUVs. Similar to this design, it has been used in various submarines, including the Russian submarines, to launch decoys and jammers. The main advantage of this design is that it uses a distance of about 1.1 meter between the outer hull and pressure hull in double-hull submarines. This design can be used at any point of the length of the submarine in the bow, middle or stern (Fig. 39) [1].

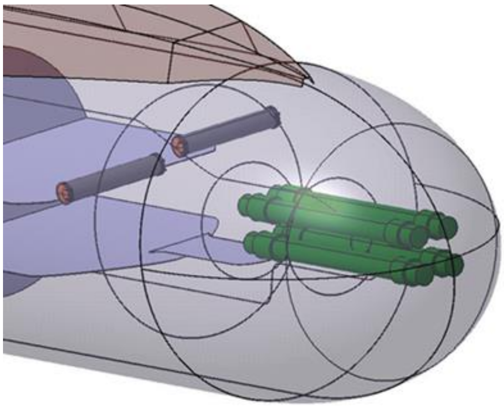
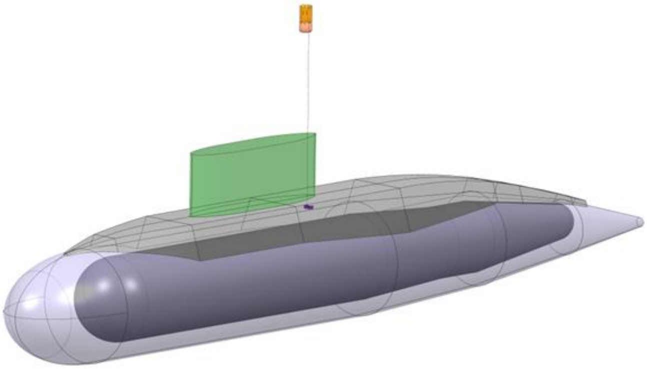


Fig 39. The location of 2 side launchers at bow for launching the REMUS100

8.10. Design 10: Use of a mast or launcher buoy released from the sailing

In this design, launcher buoys are released as buoys from inside the sailing are used. This buoy is connected to the body through a cable and hydraulic winch. According to the figure below, the launcher set is a positive buoyancy cylindrical and a watertight chamber with a height of 2.5 meters, a diameter of 1 meter, and a volume of 2 cubic meters which is located inside the sailing. Inside the buoy, there are some AUVs. This buoy is mostly used for launching AUVs. According to the figures below, six small AUVs with retractable wings can be deployed inside it. Also, this container can be used as a launcher for launching short-range missiles. In war conditions, when the submarine cannot approach the surface of the sea, by releasing this launcher buoy, it maintains its distance from the surface of the sea, and after launching the AUV or missile, it returns the buoy back to its original location inside the sailing due to the gathering of the cable by the hydraulic winch. Also, this architecture helps the submarine to launch from the water's surface even in rough ocean conditions. It is also possible to use the existing masts inside the sailing to install the UAV launcher(Fig40)[18].



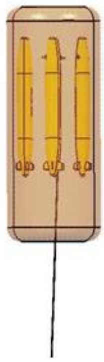


Fig 40. Positioning of the released launcher buoy for launching AUVs and missiles- A height of 10 meters or more for the release cable of a launcher from inside the sailing for the advantage of not needing to get close to the water surface to launch AUVs, drones and missiles.

8.11. Design 11: Launching AUVs from the ordinary torpedo tubes

Using the space inside the torpedo tube to launch AUVs can also be considered. According to the experience that has existed until now on the use of torpedo tubes to release divers and launch mines and rockets, they can also be used to launch AUVs, but there are two problems in this field:

- The length of the torpedo tube, which is usually about 8 meters with a diameter of about 60 centimeters, is long for the exit of a small AUV. For such a diameter, the length of the AUV is usually less than 2.5 meters, and due to this length, a long distance must be passed inside the tube. This is the reason why it is usually tried to make the tubes shorter in order to get out of the AUVs more easily and to leave the tube (launcher) immediately. Of course, the AUV comes out of the tube with its own thrust and does not need a launch device.
- Using the space of the torpedo room for the preparation and exit of AUVs may disturb the

working space of the torpedo room and is not compatible with the strict safety military standards in the torpedo room. Therefore, an attempt is made to provide a space independent of the torpedo room in the architecture of the space for the launch tubes of the AUVs and also for the preparation space of the AUVs (Fig. 41)[1].

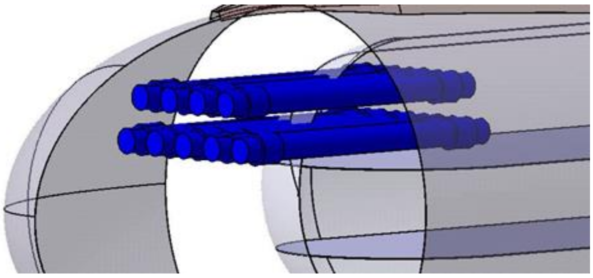


Fig 41. A view of 8 torpedo launchers

8.12. Design 12: Using a vertical launcher in SSBNs as an aquarium

This design can be implemented in SSBN submarines and use one of the vertical launchers (VLS) as an aquarium to launch drones and AUVs (an example of the idea in Fig. 42 for launching UMVs from VLS launchers). In this design, a detachable non watertight deck is installed inside one of the launchers, and the equipment for preparing and deploying the AUVs is placed inside it. To create a connection between the space inside the launcher and inside the submarine, a horizontal nozzle is installed in one launcher at the desired height so that it is possible to transfer AUVs and move the crew through it. The main advantage of this method is that it uses VLS launchers available in SSBN submarines with a suitable diameter without imposing another space on the submarine. The disadvantage of this method is that the capacity of one of the launchers to launch a missile is reduced and it needs a huge amount of flooding water for launching a small AUV (Fig 42). This water should be available in compensation tanks of submarine.

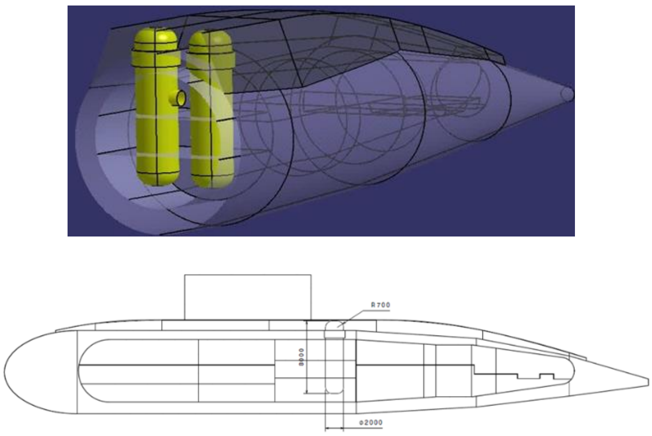


Fig 42. Using VLS to transform into an aquarium of UAVs

8.13. Design 13: Using the inclined launchers on the sides of submarine for launching AUVs, UAVs and missiles

This design, which has been implemented in the Charlie submarine and Oscar submarine of Russia, is very suitable for two-hull submarines (Fig 43). The same advantages and disadvantages of design 12 are also true here but there is a difference here that these inclined launchers are located fully outside the pressure hull. In future submarines, smaller inclined launchers can be placed between the two hulls (pressure hull and outer hull) so that it fits the length and diameter of the UMVs instead of large long-range missiles. When the launchers are smaller, less flooding water is needed, and the UMV comes out faster and easier, and a smaller installation space is needed.

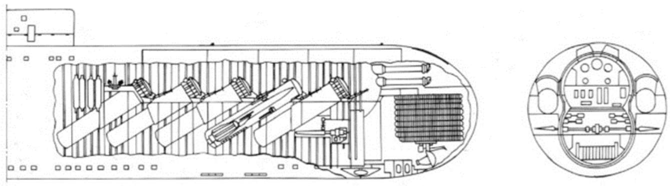


Fig 43. Charlie submarine with inclined launchers outside the pressure hull (figure from https://drawingdatabase.com/charlie-class-submarine).

9. Conclusion

This article examines 13 different architectural designs of AUVs on a base submarine (mother submarine) and lists the advantages and disadvantages of each design. The selected base submarine is the Russian Kilo class submarine, and the selected AUVs are real models available in different sizes. In selecting AUVs, it is tried to use different types with very different dimensions because the considerations for their use are different. The bottleneck of evolution in AUVs is the density of energy storage in batteries, which due to the rapid growth of battery technology, it is expected that the capabilities of AUVs in the coming years will not be comparable to their current specifications. The ability to widely use of AUVs in large manned military submarines is an important characteristic of the sixth-generation military submarines in the 21st century, and it is an important difference between them and the submarines of the 20th century. One of the challenges of military submarines in using AUVs is how to effectively store, launch, and recover them after completing the mission and returning safely and undamaged inside the submarine. Unlike torpedoes, many small AUVs are not suicidal and can be used repeatedly and are very expensive. Another important requirement is the possibility of group launch AUVs in large numbers. In order to meet these requirements in the use of AUVs, the architecture of large military submarines will undergo changes. In this article, some of these changes have been reviewed. Future submarines should select one of the available methods for launching the UMVs.

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