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RESEARCH ARTICLE

**An ethical committee approval and/or legal/special permission has not been required within the scope of this study.*

DESIGN PRIORITIZATION STUDY FOR A SEMI-SUBMERSIBLE NAVAL SHIP BASED ON FAST DECISION METHOD

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ABSTRACT

Recently, number of countries included various types of special operations crafts to their navies. One type of these crafts is called semi-submersible naval ship, which utilizes superior properties of a submarine and a surface ship. This paper presents general characteristic design features of these type of ships. Additionally, a design prioritization study based on a Fast-Decision survey was carried to determine the importance of different design features of such ships. Survey participants were chosen from experienced naval officers who served the–Navy. The responses are analyzed and presented with bar charts which shows the order of importance of the different design parameters. Results reveals that the most important operational tasks for a semi-submersible naval ship are naval special operations capability and ability to infiltrate, dodge and operate in hostile waters while the most important functional features are high maneuverability in surface operations and low acoustic detectability in underwater operations. In addition, it appears that the size of the control room and engine room is more important than the ship's ability to be transported by another vehicle. The authors are intended to make conceptual designs for semi-submersible naval ships and investigate their hydrodynamic features in future studies.

Keywords: *Semi-Submersible Naval Ship, Design Prioritization, Fast Decision Method*

YARI DALGIÇ ASKERİ GEMİLER İÇİN HIZLI KARAR ALMA METONUNA DAYALI TASARIM ÖNCELİKLENDİRME ÇALIŞMASI

ÖZ

Son yıllarda pek çok ülke donanmalarına çeşitli türlerde özel harekât gemileri eklemektedir. Bu gemilerin türü hem bir denizaltının hem de bir yüzey gemisinin üstün özelliklerini birleştirmektedir ve yarı dalgıç askeri gemiler olarak adlandırılmaktadır. Bu makale yarı dalgıç askeri gemilerin genel karakteristik tasarım özelliklerini açıklamaktadır. Ayrıca, farklı tasarım özelliklerinin ne ölçüde önemli olduğunu belirlemek amacıyla, hızlı karar alma anket araştırmasına dayanan bir tasarım önceliklendirme çalışması da yürütülmüştür. Anket çalışmasının katılımcıları Türk Donanmasında görev yapan tecrübe sahibi deniz subayları arasından seçilmiştir. Yanıtlar incelenmiş ve farklı tasarım unsurlarının önem sırasını gösteren çubuk grafikler halinde sunulmuştur. Sonuçlar bir yarı dalgıç askeri gemi için en önemli operasyonel görevlerin deniz özel harekât yeteneği ile sızma, sıyrılma ve düşman sularda operasyon yeteneği olduğunu, en önemli işlevsel özelliklerinin ise yüzey operasyonlarında yüksek manevra kabiliyeti ve su altı operasyonlarında düşük akustik iz olduğunu ortaya koymaktadır. Buna ek olarak, kumanda odası ve makine dairesi genişliğinin geminin bir başka araçla taşınabilmesine kıyasla daha önemli olduğu anlaşılmaktadır. Yazarlar gelecekteki çalışmalarında yarı dalgıç askeri gemiler için kavramsal tasarımlar yapmayı ve bu gemilerin hidrodinamik özelliklerini incelemeyi amaçlamaktadır.

Anahtar Kelimeler: *Yarı dalgıç askeri gemiler, Tasarım Önceliklendirmesi, Hızlı Karar Alma Metodu.*

1. INTRODUCTION

It is estimated that the first maritime activities date back to 4000 BC while the idea of an underwater ship dates back to the 16th century (Bevan, 1999; Davis, 1995). The underwater technology has utmost importance in the defense industry. This is understandable considering that most of the world's surface is covered by oceans and the ocean depth in open water reaches thousands of meters. Underwater ships have several advantages over surface ships which can be briefly listed as follows:

a) Most surface platforms are outfitted with limited underwater detection sensor suits and have limited engagement capabilities underwater.

b) Many long-range effective weapons on surface ships are absolute against underwater targets.

c) Satellite detection is not effective underwater.

d) Craft with underwater operational capabilities are combat effective due to their stealth features and are more flexible and have a wider operating area.

These advantages have led to the effective use of submarines since World War I. In recent years, countries have begun to procure more versatile special-operation ships in their navies in addition to the submarines. These ships can perform various multi-objective tasks and one of these special-operation ship types is called semi-submersible naval ships.

A semi-submersible naval ship is a special purpose warship that can operate both underwater and surface by utilizing the advantageous features of a submarine and of a surface ship. With water ballast operation, they can minimize their radar cross-sectional area so that they can perform some special-purpose military missions by infiltrating hostile waters.

Today number of countries have semi-submersible ships in their navies. It is understood that, on the other hand, academic research in the open literature on such ships is rather limited since, as with all naval ships, information about such ships is confidential.

Semi-submersible vessels have the superior features of both surface-operated and subsea-operated vessels. These ships, which are mostly under 25 meters in size, can reach speeds of up to 50 knots on the surface, just like a fast transport boat, and have high maneuverability. Their most distinctive feature under water is that they can operate undetected by sailing at low speed with electric propulsion. In this sense, semi-submersible military infiltration ships can be considered as fast transport boats with diving capabilities.

There are various difficulties in the design and production of semi-submersible ships because they have the superior features of both a surface ship and a submarine. Since they are mostly both diesel-driven and electric driven, they have two separate propulsion systems. Particularly when sailing on surface, ships are required to have high speed and maneuverability, and this requires providing sufficient space for two different propulsion system during the design phase. This requires increasing the beam of the ship or block coefficient of the hull. Both solutions result in an increase in hull resistance and therefore power requirement. For this reason, it is of great importance to attain a fulfilling general arrangement and hull form in the early stages of the design.

The aim of this study is to provide practical and convenient information on the design features and design constraints of the semi-submersible naval ships.

2. LITERATURE REVIEW

Semi-submersible naval ships are classified under special operations crafts combining the features of submarines and some features of surface ships. Countries including USA, Russia, North Korea and Italia developed various submersible and semi-submersible designs.

The first example of a true semi-submersible, named KETA, was built in Russian Empire in 1904 as a torpedo boat with a length of 7 meters and powered by a 10-kW motor (Rassol, 2005). Boat had a twin hull construction; lower part was for water ballast while the operator was located at the upper part. KETA was able to dive and operate under sea at 8 meters depth for only 3-5 minutes. Starting from 1970s, North Korea produced several semi-submersible ships to run agents to the South Korea which are derived from fast speed fishing boats. One of the newest class of these ships is called TAEDONG-B whose characteristics are given in Table 1 (Sutton, 2015a).

Table 1. *Main Characteristics of Taedong-B (Sutton, 2015a).*

Lenght	17 m
Beam	3,3 m
Height	3,5 m
Displacement	22 ton
Maximum speed at surface	40 knots
Dalmış halde maksimum hız	3 knots
Operating Depth	3 m
Power Plants	2 diesel engines and 2 electric motors

Taedong-B has a striking design having two electric-motor operated propellers each side of the hull in addition to the two-diesel engine operated aft propellers. Buoyancy is controlled by water ballast operations a diving angle is determined by two fins located on either side of the hull. Ship is also equipped with two torpedo tubes for defense purposes. Fig. 1 shows the profile view of Taedong-B.

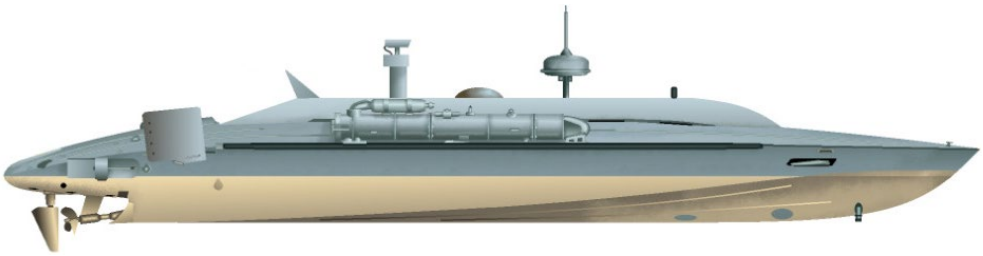

Figure 1. *Profile View of Taedong-B (Sutton, 2015a).*

SEALION (Fig. 2), a 24 m long semi-submersible ship with a planning hull, was introduced by USA Navy Forces in 2014 (Sutton, 2017). The craft was classified as combatant craft heavy and is powered by two 1100 kW diesel engines by which over 30 knots speed is attained. Crew compartment, suitable for seven crew, is located at

fore part while diesel engines and gen-sets are set about amidships and propulsion and maneuvering are achieved by two waterjets at the stern.

Figure 2. *SEALION II Combatant Craft Heavy (Sutton, 2017).*

An important example, COMBUSIN's semi-submersible (Fig. 3), which is part of the Italian Navy, was designed specifically for counter-terrorism, commando and sabotage operations and first entered service in the 1970s. All technical specifications about the ship are kept as a military secret; however, it has been observed that the ship, which resembles a powerful motorboat, is at least 13 meters long and can reach a speed of over 30 knots (Sutton, 2015b).

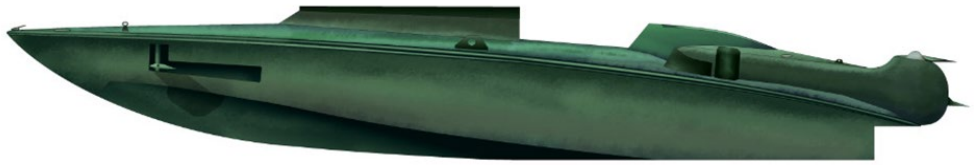

Figure 3. *COMBUSIN's Semi-submersible Boat (Sutton, 2015b).*

Another Italian submersible, which is specially designed for fast swimmer delivery, is Cos.Mo.S 'Nessie' and its details were shared by expert Lino Mancini (Sutton, 2016). This vehicle, designed for transporting 6 soldiers, had an arrow like bow form and equipped with two 500 HP diesel engines. Diesel engines were used for surface

operations while the ship is equipped with additional electric motor for under water operations. Detailed plans of Cos.Mo.S 'Nessie' are shown in Fig. 4.

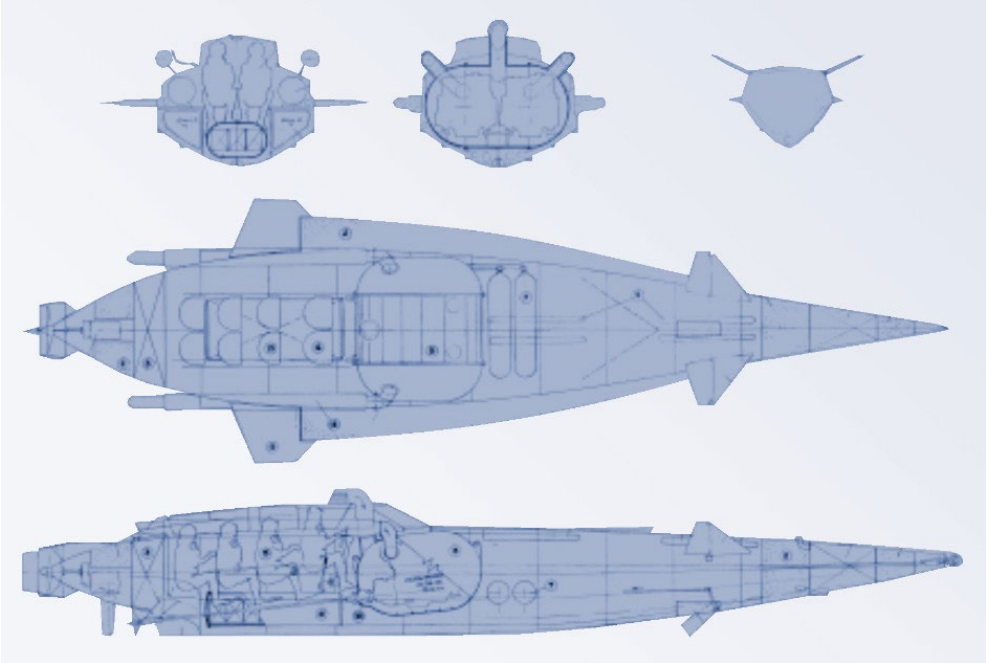

Figure 4. *Plans of the Swimmer Delivery Vehicle Cos.Mo.S 'Nessie' (Sutton, 2016).*

3. METHODOLOGY

To achieve a successful and versatile design, it is essential to avoid considering single design parameter independently since most of the times these parameters shares interacting features and losing control of the interactions of different design parameters may result in a poor outcome (Joubert, 2004). According to Burcher and Rydill (1995) all design parameters should be considered like pieces of a puzzle where any changes in a piece requires some adjustments to the other pieces. Papanikolaou (2014) considered a ship as a system, which is composed of smaller subsystems, and suggested that a ship design should be considered as a complex optimization problem where all the functional objectives and interactions of the components should be kept in view. As a result, a naval architect should look at the

whole picture when designing a semi-submersible ship and make a comprehensive prioritization in design parameters while determining all limitations to reach desired outcome.

3.1. General Features of a Semi-Submersible Naval Ship

In the last century, radar, sonar, etc. technological developments in remote sensing systems have pushed countries to add submersible and semi-submersible ships to their navies. Although semi-submersible boats are not large warships, they provide advantages especially in operations such as intelligence gathering, reconnaissance and surveillance due to their ability to hide from systems such as radar and sonar. Operational tasks of a semi-submersible naval ship can be listed as follow:

a) Intelligence, surveillance and reconnaissance,

b) Ability to infiltrate, dodge, operate in hostile waters

c) Electronic and acoustic warfare,

d) Fast Seal Delivery,

e) Naval special operations,

f) Support in amphibious operations,

g) Counterterrorism,

h) Asymmetric warfare.

In that respect, following functional features should be sustained:

a) Ability to achieve high service speed in surface operations,

b) Ability to shallow dive for under water operations,

c) Low radar and sonar detectability,

d) High maneuverability, especially in surface operations.

The main purpose of this study is to prioritize these functional features and operational tasks which directly affect the design of the ship. To do that a fast

decision questionnaire is prepared and experienced naval officers serving in the Turkish Naval Forces were asked to answer the survey questions.

3.1. Fast Decision Method

The fast decision (FD) method is used to make an optimum decision among many given alternatives swiftly. The FD method is a quasi-multi-criteria decision analysis that has been considered a significant method due to its mathematical properties of methods applicable to solve judgment problems. The appropriate data have been derived by using comparisons in which the decision-maker considered one alternative at a time, while looking and considering the whole picture. These comparisons were used to obtain the weights of importance of the decision criteria, and the relative performance measures of the alternatives. The FD method gives the suitable decision that best suits the goals and evaluates alternative solutions. The main advantage of the FD method is, unlike some other decision-making methods, the judgements are very strict, and the decision-maker sees the whole picture at once. Additionally, FD method is ranking choices in the order of their effectiveness. For these reasons, FD method is used to rank functional and operational parameters which affects the design of a semi-submersible ship.

The mathematics of the FD method is presented. The alternatives or the parameters are given by $\{Q_1, Q_2, \dots, Q_m\}$ and parameter coefficients (or weights) by $\{a_1, a_2, \dots, a_m\}$, where m is the number of compared alternatives (or the parameters). The parameter coefficients (or weights) can be given in the following form:

Parameter coefficients, a_i can be defined as:

$$a_i = \frac{1}{n} \cdot \frac{\sum_{k=1}^{n} Q_{ki}}{\sum_{r=1}^{m} Q_{ir}}, \quad i = 1,2, \dots, m \tag{1}$$

where m is the number of parameters, n is the number of survey participants, Q_{ki} is the answer of the survey participant number k, to the question number i.

Once the parameters of the decision-making process are determined, the coefficients, which determines the importance of these parameters in the total

decision-making function, can be quickly determined using FD methods. The salient points to consider here are as follows:

a) The parameters and coefficients should be included on a single page. In this way, the participants filling out the survey can see all the parameters that make up the decision-making in a single view. In this way, they can also see the other parameters while evaluating a single parameter.

b) In fact, this decision-making method is a generalization of the process in which the experts of a subject make the appropriate choice among the alternatives by self-intuition.

c) The simplicity of the scaling to be used to determine the importance of the parameters makes the work of the participant who will make the evaluation easier. There are no standard scales on this method, but the following scales (Table 2) or similar can be used:

Table 2. *The scale for the judgments used in Fast Decision Method*

Scale	**Scale**	**Judgments**
1	1	Zero important
2		Very slight important
3	2	Slight important
4		Between slight and moderate important
5	3	Moderate important
6		Between strong and moderate important
7	4	Strong important
8		Between strong and extreme important
9		Extreme important
10	5	Utmost important

4. RESULTS AND DISCUSSION

Thirty-eight naval officers with 5 – 10 years of experience in the service who serve for Turkish Navy were asked to evaluate twenty different design parameters with an FD survey. All the respondents were male and residing in Marmara region. The main advantage of the method is that the participants can see all parameters easily which enables them to consider all parameters as a whole rather than focusing each parameter one by one. As a result, a complete and comprehensive prioritization of the parameters can be attained.

Fig. 5 shows calculated parameter coefficients (PC) for different design features of a semi-submersible naval ship. Due to the formulation of the FD method, total score of the PCs equals to one, thus, graph is limited to 0.06. The figure shows that a semi-submersible should include large number of functional features; there is only a small difference between the parameter coefficients of high maneuverability in surface operations, which has the highest score (PC = 0.0588), and low visual detectability in under water operations, which has the 13th highest score (PC = 0.0569). Additionally, it can be deduced from the figure that it is of utmost importance for a semi-submersible naval ship to include following features:

a) High maneuverability in surface operations,

b) Naval special operations capability,

c) Ability to infiltrate, dodge, operate in hostile waters

while ability to be transported by another vehicle and low acoustic detectability in surface operations are less important to be included. Both largeness of the engine room and operating room have relatively less PC, which might be a facilitating factor to provide space for electrical and acoustic equipment. On the other hand, that the ship should sustain both high maneuverability and speed in surface operations while having low acoustic detectability in under water operations forms a difficulty since

these require both the usage of high-power diesel engines in surface operations while electric propulsion in under water operations.

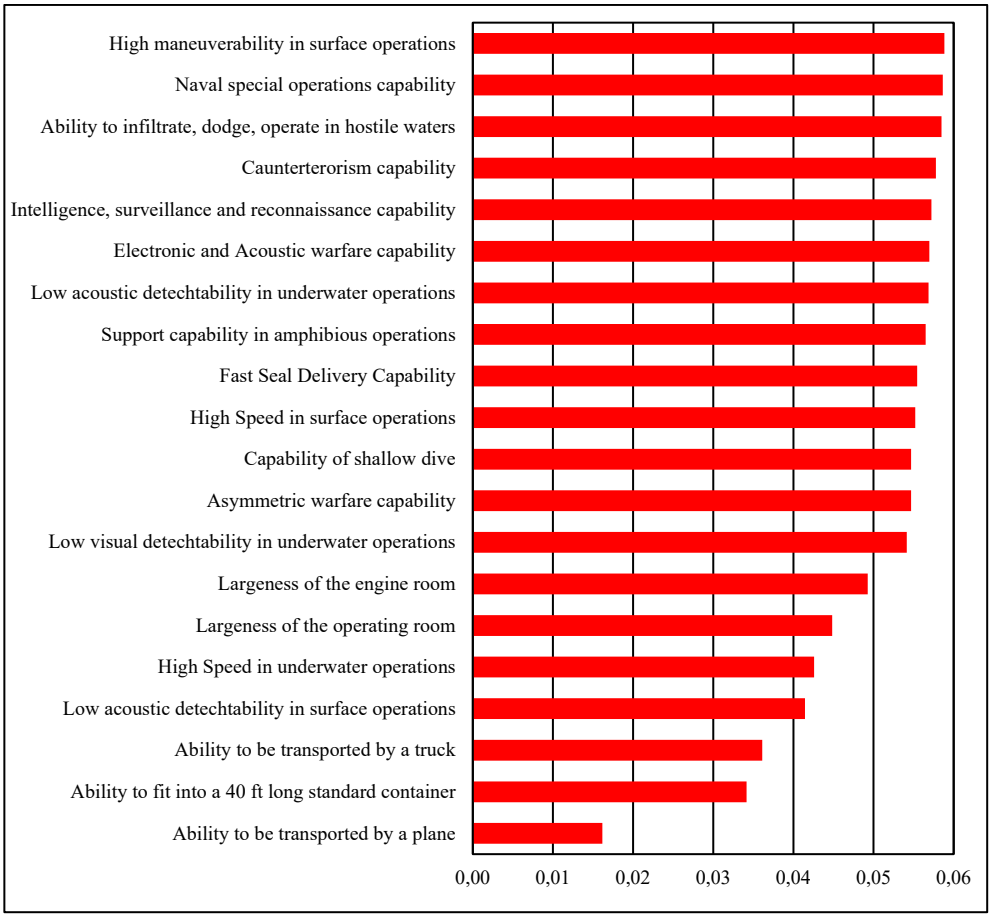

Figure 5. *Parameter Coefficients (PCs) for Different Design Parameters.*

It should be kept in mind that these parameters have implicit interrelations which means a change in any design feature might directly or indirectly affect all these parameters. Having a prioritization such as in Fig. 5 helps the designer to keep control of each parameter and avoid any undesired outcome to occur. It is also possible to group these parameters based on which feature or features of the ship

they are closely related. Fig. 6 compares the importance of the design parameters which are closely related to the operational tasks of the ship. It can be deduced from the figure that Naval special operations capability is more important than the other tasks while asymmetric warfare capability is less important than all the other parameters. It should be noted however, all parameters related to the operational tasks have close parameter coefficients.

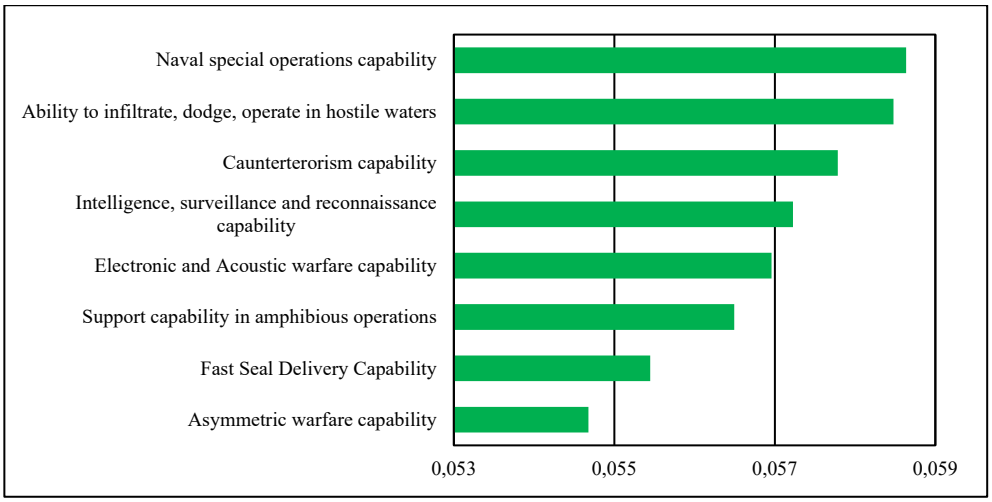

Figure 6. *Parameter Coefficients for Design Parameters Related to Operational Tasks.*

Fig. 7 compares the importance of the design parameters, which are closely related to the functional features of the ship. According to the results, high maneuverability in surface operations has the highest importance while high speed in underwater operations has the lowest importance, which is reasonable since low acoustic detectability is more important than the speed in under water operations.

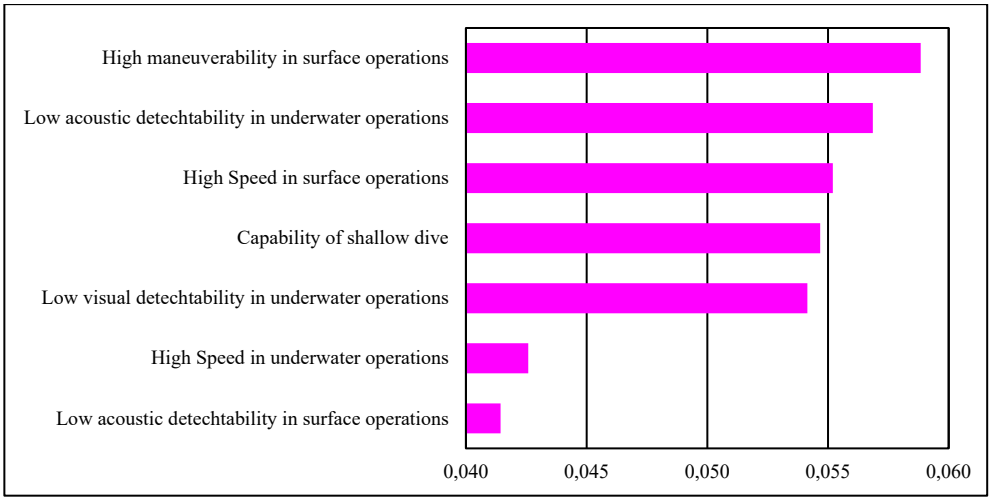

Figure 7. *Parameter Coefficients for Design Parameters Related to Functional Features.*

5. CONCLUSION

This paper presents general features of semi-submersible naval ships and investigates which operational and functional features are important to include when designing them. Design features are prioritized by analyzing the results of a questionnaire appropriate for the FD method. Thirty-seven naval officers were surveyed. The purpose of this survey is to provide practical and convenient information on the design features and design constraints of a special type of naval ships.

A semi-submersible naval ship is a special type of warship, which can be considered as a hybrid ship which operates both on surface and under water. These ships have been used by countries since the beginning of the 20th century for several operations such as sabotage, intelligence gathering and seal delivery.

Designing a semi-submersible naval ship has several difficulties since the ship should include functional and operational features of both a surface ship and a submarine. It is observed that both high maneuvering capabilities and achieving high service speed in surface operations are essential for these ships while low

observability and infiltration capabilities are profoundly important to include. One possible solution to these requirements would be including two water jets for high maneuverability and two high-powered diesel engines for high speed while additional electrical propulsion units for acoustic performance in underwater operations. Additionally, shallow diving can be achieved by a suitable water ballast system while diving angle can be controlled by additional fins located at either side of the shell.

An engineer should consider all requirements and restrictions as a whole while designing a product. It is useful at first stage to carry out a prioritization study to gain better understanding of the problem while seeing all design parameters in one graph. Results of this study can be used as a starting point of conceptual design of a semi-submersible. Authors are intended to make conceptual design of a semi-submersible naval ship and investigate its hydrodynamic performance in both surface and underwater operations.

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The authors declare no conflict of interest.

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APPENDIX

Table: Expert Questionnaire for Design Parameters

	Importance				
Design Parameter	**1**	**2**	**3**	**4**	**5**
Intelligence, surveillance and reconnaissance capability					
Ability to infiltrate, dodge, operate in hostile waters					
Electronic and Acoustic warfare capability					
Fast Seal Delivery Capability					
Naval special operations capability					
Support capability in amphibious operations					
Counterterrorism capability					
Asymmetric warfare capability					
High Speed in surface operations					
Capability of shallow dive					
High manoeuvrability in surface operations					

	Importance				
Design Parameters	**1**	**2**	**3**	**4**	**5**
High Speed in underwater operations					
Low acoustic detectability in underwater operations					
Low visual detectability in underwater operations					
Low acoustic detectability in surface operations					
Ability to be transported by a truck					
Ability to be transported by a plane					
Ability to fit into a 40 ft. long standard container					
Largeness of the operating room					
Largeness of the engine room					