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PROTECTING THE TURKISH STRAITS FROM MARITIME TERRORISM: A SCHEME TO IMPEDE PROPELLER EFFICIENCY

by

Tolga Koptu

June 2012

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PROTECTING THE TURKISH STRAITS FROM MARITIME TERRORISM: A SCHEME TO IMPEDE PROPELLER EFFICIENCY

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LIST OF ACRONYMS AND ABBREVIATIONS

AIS	Automatic Identification System
CFD	Computational Fluid Dynamics
DWT	Deadweight Tonnage
GDP	Gross Domestic Product
LBP	Length between Perpendiculars
LNG	Liquefied Natural Gas
LOA	Length Overall
LPG	Liquefied Petroleum Gas
LRAD	Long Range Acoustic Device
MT	Metric Ton
NM	Nautical Mile
NNEMP	Non-Nuclear Electromagnetic Pulse
PPT	Parts per Thousand
RPM	Revolutions per Minute
SONAR	Sound Navigation and Ranging
TCH	Tanker Chemical
TTA	Tanker Crude Oil
USD	United States Dollar
UUV	Unmanned Underwater Vehicle
VEB	Vessel Exclusion Barrier

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"Peace at home, peace in the world."

Mustafa Kemal Ataturk

I dedicate my thesis to the sailors who lost their lives while serving aboard the TCG Muavenet (DM-357) in order to keep our beloved country in peace.

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I. INTRODUCTION

A. BACKGROUND

The protection of the Turkish Straits against maritime terrorism is an important security problem that must be solved because the straits are highly vulnerable to terrorist attacks. It is relatively easy to execute a terrorist attack in the straits because of the intense maritime traffic, narrow geographical configurations and high population density. Terrorists do not need a large amount of explosives because the cargo of Liquefied Natural Gas (LNG), Liquefied Petroleum Gas (LPG) and other chemical cargo carrier ships is itself highly explosive. An explosion in the straits may cause the loss of thousands of lives, an environmental catastrophe, closure of the straits for navigation and an economic crisis. Therefore, the straits are high value targets from the point of view of terrorist organizations.

The USS Cole, the crude oil tanker Limburg and the SuperFerry-14 incidents demonstrate the ability of terrorists to execute maritime terrorism. During this research, the Kartepe ferry was hijacked in the Gulf of Izmit, Turkey. There are high value targets in and around the Gulf of Izmit: the main base of the Turkish Navy, the shore refinery of the Turkish Petroleum Refineries Corporation (TUPRAS) and the Istanbul Strait, which is just 40 NM away from the gulf. This recent incident demonstrates the threat of maritime terrorism in Turkey. Furthermore, the success of piracy attacks may encourage terrorist organizations to execute maritime terrorism.

Currently, there are lots of academic papers, technical reports and newspaper articles about the vulnerability of the Turkish Straits to maritime accidents and dangerous cargo carrier ship explosions. This research aims to go one step further and develop a solution for preventing maritime terrorism in the straits. In this study first the most probable scenario from the point of view of a terrorist organization is determined. Second, all the existing and some non-existent methods to prevent this scenario are analyzed. Finally, an underwater system is designed to impede the propeller efficiency of a ship by wrapping ropes and nets around the propeller and its hub in order to stop the ship before entering the strait.

B. PURPOSE OF THE RESEARCH

The main purpose of this research is to design an underwater system that provides an additional security to the Turkish Straits against maritime terrorism. The proposed security design targets the propeller and hub of the terrorist ship by wrapping ropes and nets. The ropes and nets are carried to the propeller and hub by unmanned underwater vehicles (UUVs), which are released from the hidden underwater structure operated with a remote control system. With such an underwater system, it is desired to impede the propeller efficiency and stop the terrorist ship before it enters the straits and prevent a possible further damage it may cause. This research followed these steps:

- Demonstrate the vulnerability of the Turkish Straits to maritime terrorism;
- Analyze the effects of a possible LNG, LPG or other chemical material explosion in the Turkish Straits;
- Determine the most probable maritime terrorism scenario in the straits;
- Analyze the existing methods of protection against the most probable scenario;
- Analyze the feasibility and applicability of currently non-existent methods of protection against the most probable scenario;
- Decide the most feasible and applicable method of protection against the terrorist ship in the most probable scenario;
- Determine the working principle of the most feasible and applicable method;

- Demonstrate the usefulness and benefits of the most feasible and applicable method by using computational methods and experimental results;
- Design a new system in order to apply the most feasible and applicable method.

C. RESEARCH QUESTIONS

To decide the most feasible and applicable method of protection against the terrorist ship in the most probable scenario (the underwater system designed to stop the terrorist ship's propeller by impeding propeller efficiency), this research addresses the following questions:

- What are the possible effects (social, economic and environmental) of executing maritime terrorism in the Turkish Straits?
- What are the shipping traffic statistics of the straits?
- What are the most explosive and dangerous cargos that are transported through the straits?
- What are the statistics, types and effects of LNG, LPG or other dangerous cargo explosions?
- What are the world's piracy statistics?
- Will the success of piracy encourage terrorist organizations to execute maritime terrorism attacks?
- What are some well-known maritime terrorism incidents?
- What are the possible methods of executing maritime terrorism?
- What are the existing methods of preventing maritime terrorism?
- What are some currently non-existent methods of preventing maritime terrorism?

- Which strait (Istanbul or Canakkale) is the most probable location of the terrorist attack?
- What are the most preferable cargo carrier ships for the terrorists to be used in an attack to straits?
- Which method will probably be used by terrorists to execute the terrorist attack?
- What is the most probable maritime terrorism scenario in the straits?
- What are the characteristics of the sample ship that will be used in the scenario?
- Is it possible to protect the straits from the most probable terrorist attack by using currently existing methods?
- Are currently non-existing methods feasible and applicable for the most probable scenario?

In order to design the underwater system, this research seeks to answer the questions:

- What are the effects of wrapping ropes and nets around the propeller and its hub?
- What are the effects of increasing hub diameter, propeller blade area, thickness, roughness, resistance and weight on propeller efficiency?
- Are there computational methods to demonstrate the success of the underwater system?
- Are there experimental methods to demonstrate the success of the underwater system?
- What are the main components of the underwater system?
- What are the probable motions of the ship after wrapping?

D. SCOPE AND LIMITATIONS

The proposed underwater system is designed based on the most feasible and applicable method of protection: to impede propeller efficiency in order to stop the terrorist ship. This method is selected to prevent the most probable maritime terrorism scenario from the point of view of terrorist organizations. Therefore, easily accessible (non-confidential) statistics and information are used for the selection process of the most probable scenario. For this reason, almost all references in Chapters II, III, IV and V are Internet based.

As studied in Chapter VI, the hub diameter, propeller blade thickness, blade area, roughness and appendage resistance will be increased after the successful wrapping of ropes and nets around the propeller and its hub. All these factors decrease the efficiency of the ship's propeller. Since there was no opportunity to conduct experiments in this research, OpenProp v2.4.6 software was used to calculate the efficiency loss due to the increase of hub diameter after wrapping. The efficiency loss caused by the other factors (i.e., an increase of the propeller blade thickness, blade area, roughness and appendage resistance) also can be calculated by using computational methods (despite the random nature of the wrapping). On the other hand, because of time limitations, a computational method could not be used to calculate the efficiency loss due to these factors. Therefore, experimental results of other researchers about propeller efficiency calculations are used to demonstrate the loss of efficiency due to these factors.

The main components of the underwater system are UUVs, a command and control station, acoustic sensors, an artificial reef, waterproof tanks, and the ropes and nets to wrap around the propeller. The functions of these components and the probable motions of the terrorist ship after wrapping are described in Chapter VII. On the other hand, the power requirements, weight and strength calculations, acoustics, underwater positioning methods, wrapping mechanism and the material selection are not studied because of time limitations of this research.

E. BENEFIT OF THE RESEARCH

The benefit of the research may be separated into two parts:

- The information and analyses that are included in the research,
- The application of the underwater system that is designed to stop a terrorist ship by wrapping ropes and nets around the propeller and its hub.

1. Information and Analyses

The decision process of the most probable maritime terrorism scenario contains lots of statistical and historical data about the Turkish Straits, their shipping traffic, maritime terrorism incidents, piracy, LNG, LPG and other chemical cargo explosions, methods of executing maritime terrorism and existing and non-existent methods of preventing maritime terrorism. On the other hand, the solution process against this scenario contains computational and experimental results about calculating the loss of propeller efficiency in order to stop a ship under control of the terrorists. All this information may be useful for researchers and organizations that are interested in preventing maritime terrorism and calculating the loss of propeller efficiency.

2. The Application of the Underwater System

Should it be deployed, this system can be used both in peace and wartime. The Turkish Navy and Coast Guard Commands can use and benefit from the underwater system.

a. Peace Time

The main purpose of the underwater system is to prevent a maritime terrorist attack by stopping a ship that is under the control of terrorists. If the system works properly, there will be a significant propeller efficiency loss, and the ship will be stopped before entering the strait. The Turkish Navy and Coast Guard Commands have boarding teams that can execute an operation to take control of the ship from the terrorists. On the other hand, an unsuccessful boarding leaves no time for a second operation; or the arrival of late intelligence about a terrorist ship already close to the entrance of the strait, there is currently no way to stop the ship. The authorities must have alternative methods besides boarding. Finally, boarding is not a guaranteed solution, so the underwater system will provide an alternative solution.

Second, the underwater system will provide a non-lethal solution to maritime terrorism attacks with ships. In this way, it will be possible to stop the ship without using any kind of weapons. Using weapons may cause explosions, damage and sinking of the terrorist ship with the loss of lives and an environmental catastrophe.

Third, if a terrorist organization has information or intelligence about this underwater system, they will probably change their minds about the method of attack. The terrorists may decide to not use an explosive cargo carrier ship. Therefore, a possible method of executing maritime terrorism will be eliminated.

The underwater system also can be used to protect shore facilities and harbors against maritime terrorism. Finally, the artificial reef part of the underwater system can serve as a home to fish for many years and contribute to the sustainable fishing industry.

b. Wartime

The underwater system can be used to stop enemy warships. The system may force an enemy to spend extra time and effort. Besides, it may serve as a deterrent to enemy forces, forcing them to change their plans or quit their mission. Also, the system may create a surprise effect (similar to sea mines) and reverse the tactical situation to the advantage of the other side. Even if enemy has intelligence about the underwater system, the ambiguity of the position information negatively affects the enemy’s operation.

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II. TURKISH STRAITS

A. OVERVIEW

The Republic of Turkey is located where Europe, Asia and Africa are closest to each other. Turkey is bordered by eight countries: Greece, Bulgaria, Georgia, Armenia, Azerbaijan, Iran, Iraq and Syria. The country has a unique geostrategic importance at the center of the Balkans, Caucasus, Middle East, Black Sea and Mediterranean Sea.

Figure 1. Location of Turkey (From [1])

Turkey was the world's eighteenth most crowded country with the population of 74.7 million people at the end of the year 2011. Turkey also had the world's eighteenth largest economy based on Gross Domestic Product (GDP) in 2011 [2], [3], [4].

Turkey is not only a cultural but an energy bridge between Europe and Asia. The importance of Turkey increases simultaneously with European countries' increasing dependency on Caspian and Middle Eastern oil and gas. The Turkish Straits are a key passage in the energy routes.

The Turkish Straits are located in the northwestern part of Turkey and separate Europe and Asia. The Istanbul Strait (also known as the Bosphorus), Canakkale Strait (also known as the Dardanelles) and the Sea of Marmara generate the 164-nautical-mile (NM)-long Turkish Strait system. The Istanbul Strait connects the Black Sea to the Sea of Marmara, and the Canakkale Strait connects the Sea of Marmara to the Aegean and Mediterranean Seas [5].

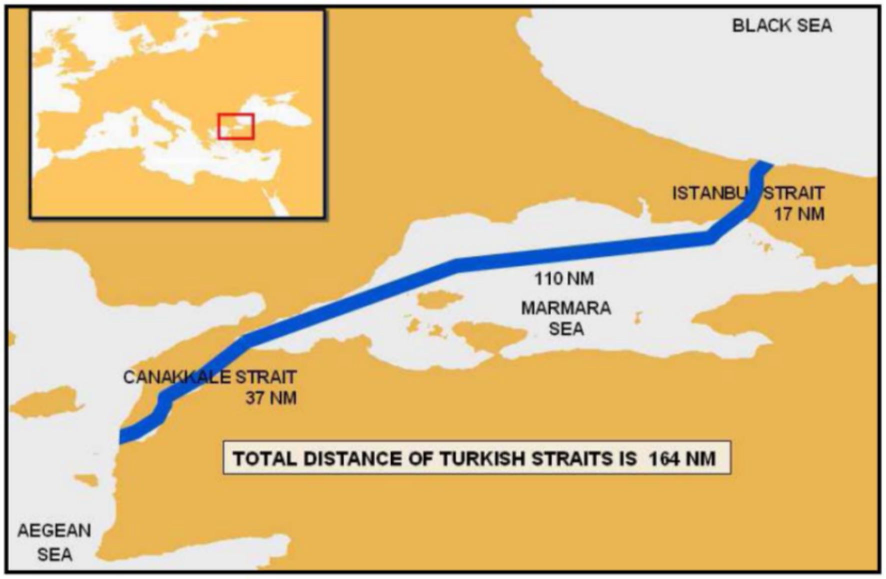

Figure 2. Turkish Strait System (From [5], [6])

B. ISTANBUL STRAIT

The Istanbul Strait is a 17-NM-long waterway between the Black Sea and the Sea of Marmara. It is the narrowest natural waterway used for international navigation with an average width of 0.81 NM. The strait has a maximum width of 1.85 NM and a minimum width of 0.38 NM. The width of the strait is 1.798 NM at the northern entrance and 1.526 NM at the southern entrance [7], [8].

The average depth of the strait is 65 meters in the shipping traffic route. The depth varies from 36 to 124 meters, the greatest depth located in the midstream of the strait [7].

There are north-to-south surface currents and south-to-north undercurrents in the strait due to the density difference between the Black Sea and the Sea of Marmara. The surface current speed is up to 4 knots in the strait. The peak current speed may reach 7-8 knots in narrow sections [7], [9].

The strait had minimum and maximum sea temperatures of 7.1 and 26.3°C (Celsius) in 2010. The salinity of the strait varies from 16 to 22 ppt (parts per thousand) [10], [11].

Figure 3. Istanbul Strait (From [5])

The strait divides the city of Istanbul, the most crowded city of Turkey, into two halves. There were 13,624,240 people living in Istanbul at the end of 2011 (18.2% of Turkey's population) [2].

Istanbul is the economic center of Turkey, producing 27% of the national gross domestic product (GDP) and 38% of the total industrial output [12].

C. CANAKKALE STRAIT

The Canakkale Strait, a 37-NM-long waterway between the Sea of Marmara and the Aegean Sea, is a natural waterway used for international navigation. The width of the strait varies from 0.75 to 3.7 NM, and its average depth is 55 meters. Just like the Istanbul Strait, there is a surface current from north-to-south and an opposite undercurrent from south-to-north. The surface current speed exceeds 3.5 knots in some regions [13], [14], [15].

The strait had minimum and maximum sea temperatures of 8 to 26.2^{o}C (Celsius) in 2010. The salinity of the strait varies from 22.7 to 39.1 ppt [10], [16].

Located beside the strait, the city of Canakkale had a total population of 486,445 people at the end of 2011 [17]. The economy depends on agriculture and the fishing industry.

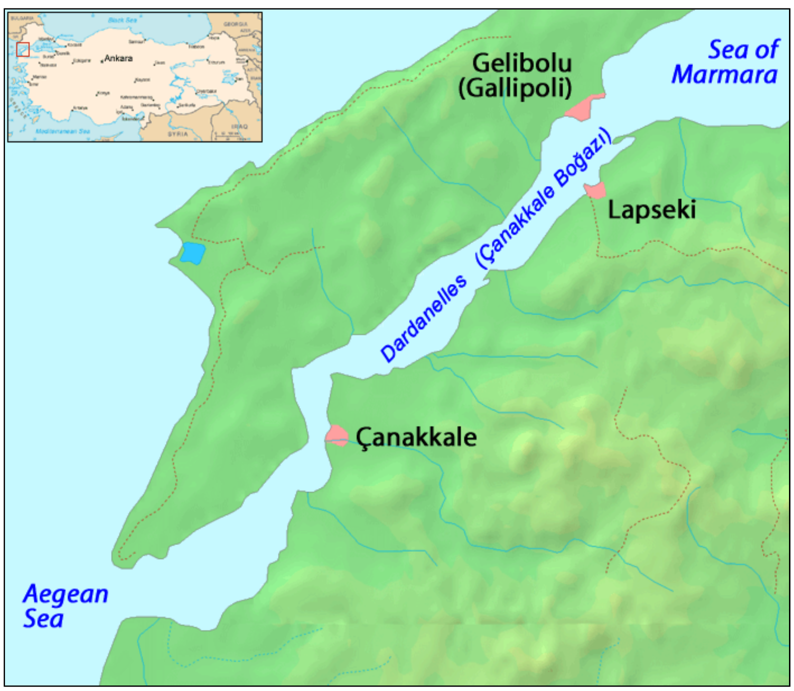

Figure 4. Canakkale Strait (From [13])

D. MARITIME TRAFFIC STATISTICS

The Turkish Straits are the only waterway that accesses the Black Sea and Central Asian countries. The annual average number of the ships passing through the Turkish Straits is 50,000 [18], [19]. The straits are one of the busiest chokepoints of the world.

Chokepoint/Critical Routes	Traffic (Number of Ships/Year)	Volume (Containers/Year)
Strait of Malacca	50,000	30,500,000
Turkish Straits	50,000	14,625,000
Strait of Hormuz	25,455	9,545,455
Suez Canal	16,000	9,900,000
Panama Canal	13,000	9,495,455
Bab el-Mandab	3,920	840,000
Russian Oil and Gas Ports	2,545	1,145,455

Table 1. Global Shipping Chokepoints Comparison (From [18])

Shipping Traffic Statistics of Istanbul Strait (Last 15 Years)					
Year	Total Number of Ships	200 Meters		500 Gross Ton	
		Less	Greater	Less	Greater
1997	50,942	44,455	6,487	5,087	45,855
1998	49,304	47,361	1,943	4,475	44,829
1999	47,906	45,738	2,168	3,552	44,354
2000	48,079	45,876	2,203	3,345	44,734
2001	42,637	40,184	2,453	2,155	40,482
2002	47,283	44,170	3,113	1,932	45,350
2003	46,939	44,016	2,923	1,782	45,157
2004	54,564	51,512	3,052	2,107	52,457
2005	54,794	51,291	3,503	1,610	53,184
2006	54,880	51,227	3,653	2,176	52,704
2007	56,606	52,953	3,653	2,138	54,468
2008	54,396	50,485	3,911	1,800	52,596
2009	51,422	47,551	3,871	1,128	50,294
2010	50,871	47,248	3,623	1,377	49,494
2011	49,798	45,998	3,800	1,046	48,752

Table 2. Shipping Traffic Statistics of Istanbul Strait (After [19])

Shipping Traffic Statistics of Canakkale Strait (Last 15 Years)					
Year	**Total Number of Ships**	**200 Meters**		**500 Gross Ton**	
		Less	**Greater**	**Less**	**Greater**
1997	36,543	28,032	8,511	1,117	35,426
1998	38,777	36,383	2,394	1,482	37,295
1999	40,582	38,014	2,568	1,492	39,090
2000	41,561	38,864	2,697	1,398	40,163
2001	39,249	34,489	2,960	936	38,316
2002	42,669	39,004	3,665	689	41,980
2003	42,648	38,925	3,723	677	41,971
2004	48,421	44,052	3,919	1,327	47,094
2005	49,077	44,585	4,492	1,211	47,866
2006	48,915	44,070	4,845	1,404	47,511
2007	49,913	44,968	4,945	1,873	48,040
2008	48,978	43,755	5,223	844	48,134
2009	49,453	44,277	5,176	615	48,838
2010	46,686	41,588	5,098	598	46,088
2011	45,379	39,885	5,494	572	44,807

Table 3. Shipping Traffic Statistics of Canakkale Strait (After [19])

The dense marine traffic of the straits increases the risk of maritime accidents that could threaten public safety. Strong surface currents and the sinusoidal shape of the straits, with sharp turns, are other characteristics that heighten this risk. There have been serious accidents in the history of the straits. The worst scenario today is an accident involving a ship carrying hazardous cargo.

An accident in the straits may cause:

- Loss of thousands of lives,
- An environmental catastrophe,
- The closure of the straits for navigation,
- An economic crisis.

There is a dense marine traffic of hazardous/dangerous cargo carrier ships in the straits. These types of ship carry liquefied petroleum gas (LPG), crude oil and oil products between the Black Sea littoral countries and Turkey, Europe, North Africa and the Americas. They carry liquefied natural gas (LNG) from Algeria and Nigeria to Turkey. Other flammable and explosive chemical materials like ethylene, propylene, and ammonium nitrate are transported through the straits.

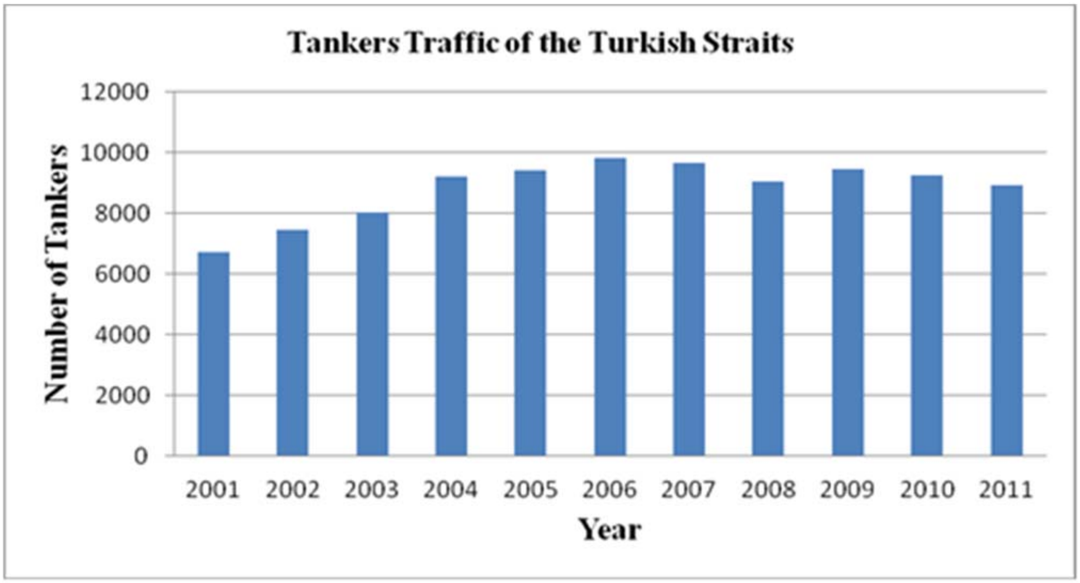

Figure 5. Tanker Traffic Statistics of The Turkish Straits (After [19])

E. MARITIME TERRORISM IN TURKISH STRAITS

The dense marine traffic of flammable and explosive cargo carrier ships and the possibly catastrophic effects of an explosion in the straits would have on public safety, the environment and the world economy may attract the attention of a terrorist organization. One of the main reasons the straits attract attention is the fact that there is no need for a large amount of explosives to carry out an attack. Terrorists do not need a large amount of explosives because the ship's cargo, itself, is highly volatile. Even without explosives, these types of ship become a weapon in case of collision. In conclusion, maritime terrorism using LNG, LPG or other flammable or explosive cargo carrier ships is respectively easy and preferable to execute, and it threatens catastrophic results. Therefore, protection of the straits against maritime terrorism is an important security problem.

Another explosive/weapon that can be used in a maritime terrorism scenario is the so-called weapons of mass destruction (WMD): chemical, biological, radiological, and nuclear (CBRN) weapons. WMD can be carried by any type of vessel and then exploded in the Turkish Straits. WMD are not as easily accessible as conventional explosives, and there is an international effort to prevent their use. Obtaining and using WMD requires a high level of knowledge and experience for a terrorist organization. For all these reasons, this method probably will not be the first choice of terrorists. Therefore, preventing WMD attacks are not directly analyzed in this research.

Protection against terrorism mainly depends on intelligence. With such intelligence, authorities must take actions to prevent terrorist attacks. The purpose of this research is to improve the capabilities of the Turkish Navy and Coast Guard Commands against maritime terrorism. In this study, the main threat and concern is the LNG, LPG or other flammable/explosive cargo carrier ships. Methods of stopping these ships under the control of terrorists are analyzed in a very detailed manner in this research to improve these capabilities. These methods are also applicable for stopping ships loaded with WMD.

III. MARITIME TERRORISM

A. FROM PIRACY TO MARITIME TERRORISM

Piracy is an important threat to maritime shipping industry. Shipping routes close to unpopulated shores have a high risk of piracy. Africa and South East Asia, especially, have dangerous waters for piracy. Somali pirates conducted 44 successful ship hijackings out of a global total of 48 in 2010 [20].

Total number of ships attacked, January to December 1995-2010															
1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
188	228	248	202	300	469	335	370	445	329	276	239	263	293	410	445

Table 4. World's Piracy Statistics (After [21])

The number of pirate attacks in Africa has increased in recent years.

Regional number of ships attacked, January to December 2005-2010							
Year	**Total**	**South East Asia**	**Far East**	**Indian Subcontinent**	**Americas**	**Africa**	**Rest of the World**
2005	276	102	20	36	25	80	13
2006	239	83	5	53	29	61	8
2007	263	70	10	30	21	120	12
2008	293	54	11	23	14	189	2
2009	410	46	23	30	37	266	8
2010	445	70	44	28	40	259	4

Table 5. World's Regional Piracy Statistics (After [21])

Basically, a pirate attack may have three results. The crew may lose their lives, shipping companies may lose money and the world's economy may be negatively affected. The cost of maritime piracy to the world's economy is estimated to be from 7 to 12 billion USD (U.S. dollars) per year. Ransoms, insurance, re-routing, and security compose the main parts of this cost [20].

Successful attacks by pirates may encourage terrorist organizations to conduct maritime terrorism. Six conditions may attract the attention of terrorist organizations to maritime terrorism:

- The significant effect of maritime terrorism to public safety, the environment, and economy,
- The current number of successful ship hijackings,
- The relatively slow speed of commercial ships,
- The relatively large bodies of commercial ships,
- The large number of unprotected, cruising commercial ships,
- The easy availability of intelligence (Terrorists can easily find the real time positions of commercial ships by checking Automatic Identification System (AIS) websites, for example http://www.marinetraffic.com/ais/)

The main physical targets of maritime terrorism are military and commercial ships, mega-cities and harbors, maritime platforms and shore facilities.

These are the well-known maritime terrorism incidents:

1. The USS Cole Incident

Terrorists executed a suicide attack on the U.S. Navy destroyer USS Cole on October 12, 2000, while she was in the port of Aden. They used a small boat loaded with explosives. Seventeen crew members were killed, and 39 were injured [22].

Figure 6. After Suicide Attack to USS Cole (From [23], [24])

2. Crude Oil Tanker Limburg Incident

The double hull crude oil tanker Limburg was rammed by a fast small boat in 2002 in the Gulf of Aden. The small boat was loaded with explosives. Double hull construction prevented the sinking of the tanker. One crew member was killed, and 12 crew members were injured. Almost 90,000 barrels of oil were spilled [22].

Figure 7. After Suicide Attack on to Supertanker Limburg (From [25], [26])

3. SuperFerry-14 Bombing Incident

Terrorists placed a television set containing a TNT bomb on board the SuperFerry-14 on the 27th of February, 2004. The explosion occurred during the ship's cruise in Manila Bay, Philippines. One hundred sixteen people were killed. This is the world's deadliest maritime terrorist attack [27].

Figure 8. After Bombing of Superferry-14 (From [28], [29])

4. Kartepe Ferry Incident

During this research, a terrorist organization named the Kurdish Workers' Party (PKK) executed a maritime terrorism activity in Turkey. This is the first maritime terrorism attempt by the PKK. In the Gulf of Izmit in November 2011, a terrorist hijacked a ferry with 18 passengers and 6 crew members on board. The terrorist was a suicide bomber wearing a bomb vest [30].

Figure 9. Gulf of Izmit (After [30])

There are high value targets in and around the Gulf of Izmit, any of which might have been targets of the terrorists. Golcuk, the main base of the Turkish Navy, is in the gulf, and the Turkish Petroleum Refineries Corporation (TUPRAS) has the biggest shore refinery of Turkey in that area. The Istanbul Strait is just 40 NM away from the gulf.

The Turkish Navy and Coast Guard Commands conducted the counter-operation together. A seal team of the Turkish Navy boarded the ferry 12 hours into the hijacking and killed the terrorist before he activated the explosives.

Figure 10. Kartepe, the Hijacked Ferry (From [30])

B. POSSIBLE METHODS OF EXECUTING MARITIME TERRORISM

The USS Cole, the crude oil tanker Limburg, the Superferry-14, and the Kartepe ferry incidents demonstrate the threat of maritime terrorism. There are a number of ways to execute a terrorist attack to cause an explosion on or take control of a target ship. The U.S. Government Accountability Office's "Maritime Security Report" is used to construct the main body of possible methods of executing maritime terrorism [31].

1. Attacks by other Vehicles

Terrorists can use explosive-loaded small vehicles to conduct this type of attack. WMD also can be loaded in the vehicles. The type of cargo carried by the target ship (for example, LNG or LPG), the characteristic of the explosives and payload of the small boat mainly determines the results of the attack.

There has been great progress in unmanned aerial, surface and underwater vehicle technologies in recent years. Even though these vehicles have payload limitations today, they can be used for terrorist attacks in the near future.

Basically, there are three types of vehicles that can be used in these attacks.

a. Small Boat Attack

Terrorists may use both remotely operated and crewed (suicide attack) small boats for attacks. Today, there are different types of unmanned surface vehicles (USVs) which are in use for military applications.

Figure 11. Manned and Unmanned Small Boats (From [32], [33])

b. Small Aircraft Attack

Terrorists may use explosive-laden small aircraft. Both remotely operated and crewed (suicide attack) small aircraft can be used. Today, there are different types of unmanned aerial vehicles (UAVs) in use for various applications.

Figure 12. Manned and Unmanned Small Aircraft (From [34], [35])

c. Small Underwater Vehicle Attack

Terrorists may use explosive-loaded small underwater vehicles. Both remotely operated and crewed (suicide attack) small underwater vehicles can be used. Today, there are different types of crewed small submarines and unmanned underwater vehicles (UUVs) which are in use for various applications.

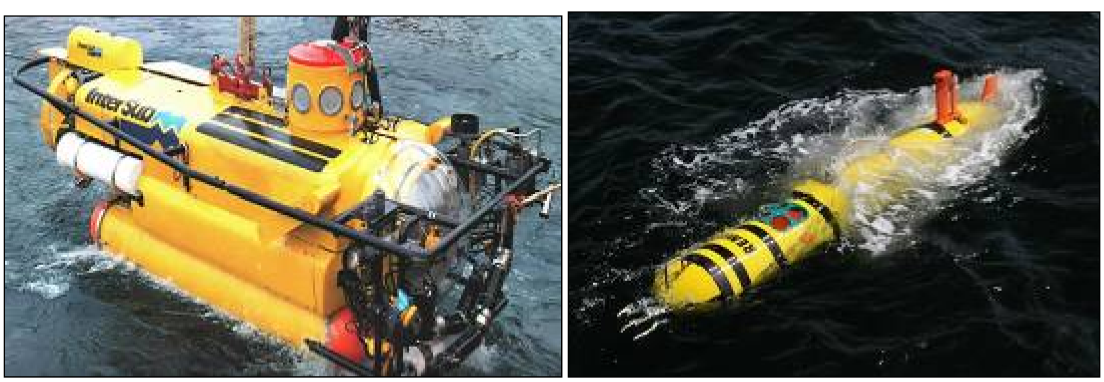

Figure 13. Manned and Unmanned Underwater Vehicles (From [36], [37])

2. Shoulder-Fired Missile Attack

Using shoulder-fired missiles is another method of executing maritime terrorism. These missiles can be launched both from land and boats. Narrow straits like the Strait of Malacca and the Turkish Straits are highly vulnerable to this type of attack. If the missile hits the bridge-deck of the target ship during its passage through the narrow strait, it may cause a collision or grounding. On the other hand, if the target ship has dangerous cargo, these missiles may cause a strong explosion.

Figure 14. Example of a Shoulder-fired Anti-armor Missile (From [38])

3. Hijacking

Terrorists may use small boats or helicopters for boarding the target ships, afterwards taking control of the ships by using weapons. Subsequent to the successful hijacking, they will have two options: colliding with another ship, platform or shore facility, or cause an explosion using explosives.

4. Crew Conspiracy

Preventing terrorists from boarding the target ship is not an absolute solution. Some of the crew may be members of a terrorist organization, and they may take control of the ship. Similar to the hijacking scenario, they will have two options: collide with another ship, platform or shore facility, or cause an explosion by using explosives.

5. Mines and Controlled Bombs

Terrorists may use harbor mines, remotely controlled bombs or time bombs to damage the target ship. These bombs can be activated during the cruise of the ship.

6. Divers/Swimmers

Underwater attack by divers is a possible method, if the target ship is not cruising.

C. METHODS FOR PREVENTING MARITIME TERRORISM

The main body of preventative methods to terrorist attack is based on C.D. Epp's thesis [39].

1. Existing Methods to Prevent a Terrorist Attack to a Target Ship or Take Control of the Ship from the Terrorists

a. Escorting the Ships while Cruising in Critical Waters

Escorting ships is an effective solution to prevent small boat attacks and boarding by terrorists. Today, the Coast Guard and Naval forces escort ships cruising in critical territorial waters, especially in the straits and entrance to harbors. NATO Maritime Group's mission against piracy in Somali is a well-known example of escorting in international waters.

b. Patrolling around Maritime Platforms and Shore Facilities

The Coast Guard has a mission of patrolling the water of important maritime platforms and shore facilities. This method prevents small boat attacks against these platforms and facilities.

c. Using Non-Lethal Weapons

The crew of the ship may use an electric fence, fire nozzle with pressurized water, optical laser distracter (a dazzle gun), Long Range Acoustic Device (LRAD) and other types of non-lethal weapons to prevent boarding by terrorists.

d. Stopping the Propeller of a Small Boat

Currently, there are two different systems to stop the propellers of small boats. These systems have size limitations.

(1) Boat Trap. The U.S. Coast Guard is using a non-lethal system called the "boat trap." The principle of the system is using ballistic nets dropped from helicopters to wrap the propeller of the terrorist boat. The system was tested many times in 2005 and stopped 100% of small boat targets [40]. This is an effective method against both maritime terrorism and piracy.

Figure 15. Deploying of Boat Trap from Coast Guard Helicopter (From [41])

Figure 16. Boat Trap: before and after Wrapping (From [41, 42])

(2) Pirate Trap (P-trap). This method protects cruising ships against piracy boarding. The system carries thin lines around the ship on both sides and at the stern and is suspended by booms. These thin lines float at the waterline. Whenever a small boat gets into this protected area, these lines wrap around the propeller, stop the boat, and prevent boarding [43].

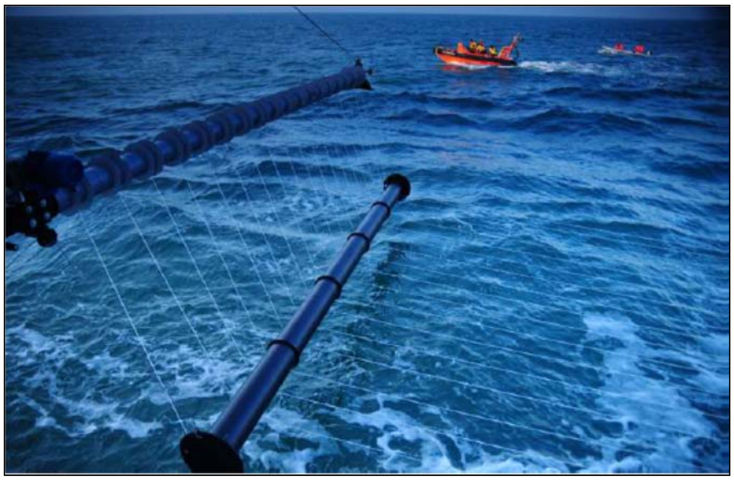

Figure 17. P-trap Application (From [43])

e. Using Scanning Devices to Find the Terrorists and Bombs

The control of containers while a ship is at port may prevent a possible attack. There are different types of devices to detect nuclear and dirty bombs. A dirty bomb is the combination of conventional explosives and radioactive materials.

f. Early Detection Systems

Using infrared camera systems, audio detection and other types of sensors may prevent a possible attack.

g. Having Security Teams on Board Commercial Ships

Having a professional security team on board increases the security of the ship above the level maintained by the crew alone.

h. Boarding

In most countries, the Coast Guard and Navy have special boarding teams trained to execute boarding operations on hijacked ships and take control of the ship from the terrorists. Currently, this is the only way to take control of ships without damaging them. Boarding teams can be deployed either from helicopters or small boats.

i. Gunfire by Warships, Aircrafts, or Land-Based Platforms

The hijacked ship can be attacked externally. However, applying this method is dangerous to the hijacked dangerous cargo ships. Gunfire may cause an explosion and lethal consequences, including an environmental catastrophe. Therefore, this method is inapplicable in some cases or places, like crowded straits and ports. On the other hand, these results are acceptable if compared with the death of thousands of innocent people.

j. Barriers

Using barriers is an effective solution in narrow straits and the seaward entrances of shore facilities. These barriers may easily prevent small boat attacks. As an example, Whisprwave's Vessel Exclusion Barrier (VEB) is able to completely stop a 35-foot (10.67 meters) vessel traveling at a speed of 43.5 knots [44]. This method has begun to play an important role in port security. However, the method has limitations: It is impossible to stop larger attack boats and cannot be used to protect ships.

Figure 18. Barriers for Stopping Small Boat Attacks (From [44])

k. Tugboats

Using high powered tugboats can be an effective solution against light displacement terrorist ships and boats. Tugboats may change the course of a ship.

Figure 19. A Typical Tugboat (From [45])

2. Currently Non-Existent Methods to Prevent a Terrorist Attack on a Target Ship or Take Control of the Ship from the Terrorists

a. Stopping the Propeller

Rope, wire, and/or nets can be wrapped around the terrorist ship's propeller. In this way, the propeller can be stopped, or at least the propeller's thrust and efficiency can be decreased. As mentioned before, the U.S. Coast Guard is using a system to stop a small boat's propeller [41]. This system has size limitations. Currently, there is no system to stop a larger ship's propeller.

b. Damaging the Propeller

Currently, there is no system to damage a ship's propeller. Even in the future, this method will have a restricted application because damaging the propeller may cause a hole in the hull of the ship, causing the ship to lose buoyancy. Uncontrolled damage may result in the sinking of the ship.

Figure 20. Propeller and Rudder of a Ship (From [46])

c. Impeding Steering by Damaging the Rudder

Currently, there is no system to impede the steering of a terrorist ship. Similar to the situation with a propeller, damaging the rudder may cause a hole in the hull of the ship. Therefore, the ship may lose buoyancy. Uncontrolled damage may result in the sinking of the ship. On the other hand, beyond traditional rudders and propellers, there are new systems that control ship course and propulsion, like the Azimuth Thruster. In this system, rudder and propeller are combined. There is no separate rudder.

Figure 21. Combined Propeller and Rudder (From [47])

d. Stopping the Engines by Interrupting the Air Flow

Currently, there is no system to interrupt air flow to the engines. In the future, interrupting air flow to the ship's engines is a possible solution to stop the engines of a terrorist ship.

e. Restricting Visibility

Currently, there is no system to restrict the visibility of a terrorist ship.

f. Damaging all the Electronic Systems of the Ship by Non-Nuclear Electromagnetic Pulse (NNEMP)

An NNEMP weapon may damage electronic systems and devices of a ship. "The effect of small e-bombs has proven to be sufficient for certain terrorists or military operations. Examples of such operations include the destruction of certain fragile electronic control systems of the type critical to the operation of many ground vehicles and aircraft" [48]. Currently, there is no NNEMP weapon for damaging the electronic devices of a terrorist ship.

g. Changing the Course of the Ship by Underwater Explosions

Changing the course of the terrorist ship may prevent a collision. This method will be useful to protect critical maritime platforms, harbor entrances and shore facilities. Currently, there is no underwater explosion system for changing the course of terrorist ships to prevent collusion.

h. Clogging the Seawater Inlets of the Engine's Cooling System

Generally, lubrication oil is cooled by freshwater, and the freshwater is cooled by seawater in marine engines. Inlets for the seawater are located on the underwater hull of the ships. Clogging the seawater inlets will raise temperatures in the engines, forcing the engine to stop. Currently, there is no system for clogging the seawater inlets of the cooling system of a marine engine.

i. *Remotely Controlled Signals to Stop the Ship's Engines*

Today, almost all marine engines have electronic command and control systems. If a marine engine manufacturer designs an engine that can be stopped by a remotely controlled signal, it will be easy to stop the ship. Currently, there is no system for stopping an engine by remotely controlled signals.

3. Summary of the Methods for Preventing Maritime Terrorism

Preventative Methods	Existing	Non-Existent
Escorting the Ships While Cruising In Critical Waters	X	-
Patrolling around the Important Maritime Platforms and Shore Facilities	X	-
Using Non-Lethal Weapons	X	-
Stopping the Propeller of a Small Boat	X	-
Using Scanning Devices to Find the Terrorists and Bombs	X	-
Early Detection Systems	X	-
Having Security Teams on Board of the Commercial Ships	X	-
Barriers	X	-
Boarding	X	-
Gunfire	X	-
Tugboats	X	-
Stopping the Propeller	-	X
Damaging the Propeller	-	X
Damaging the Rudder	-	X
Interrupting Air Flow	-	X
Restricting Visibility	-	X
NNEMP	-	X
Underwater Explosions	-	X
Clogging the Seawater Inlets	-	X
Remotely Controlled Signals	-	X

Table 6. Summary of the Methods for Preventing Maritime Terrorism

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IV. ANALYSIS OF LNG, LPG AND OTHER DANGEROUS CARGO

A. OVERVIEW

The characteristics and hazards of the LNG, LPG and other flammable/explosive cargo are analyzed in this chapter. Based on this analysis, the next chapter will seek to answer two basic questions: Are tankers that carry LNG, LPG and other such chemicals and that pass through the Turkish Straits attractive targets for terrorists? If they are, which are the best targets from terrorists' point of view?

The number of pirate attacks has increased in recent years. The success of piracy may boost maritime terrorism. Pirates hijack ships for ransom, but if terrorists hijack explosive cargo ships, the results will probably be catastrophic.

Number of Hazardous/Dangerous Cargo Ships Attacked January to December 1995-2010					
Year	**Total**	**Tanker Chemical / Product**	**Tanker Crude Oil**	**Tanker LNG**	**Tanker LPG**
1995	188	2	25	1	7
1996	228	16	25	1	10
1997	248	6	37	4	7
1998	202	9	31	3	8
1999	300	18	52	2	5
2000	469	22	91	-	12
2001	335	25	55	-	8
2002	370	25	44	-	13
2003	445	49	42	-	14
2004	329	56	17	-	13
2005	276	43	22	-	5
2006	239	35	9	-	4
2007	263	52	25	1	5
2008	293	55	30	-	6
2009	410	69	41	1	5
2010	445	96	43	1	7

Table 7. Hazardous/Dangerous Cargo Ships Piracy Statistics (After [21])

There is a dense traffic of hazardous/dangerous cargo ships in the Turkish Straits. Some of these cargos have flammable/explosive physical properties. These ships carry LPG, crude oil and oil products between the Black Sea littoral countries to Turkey, Europe, North Africa and the Americas. They carry LNG from Algeria and Nigeria to Turkey. Other flammable/explosive chemical materials like ethylene, propylene, and ammonium nitrate are also transported through the straits.

There are two LNG terminals in Turkey. One of them is in the coast of Sea of Marmara (BOTAS-Marmara Ereglisi LNG Terminal), and the other one in Aegean Sea coast (EGEGAZ-Aliaga LNG Terminal) [49].

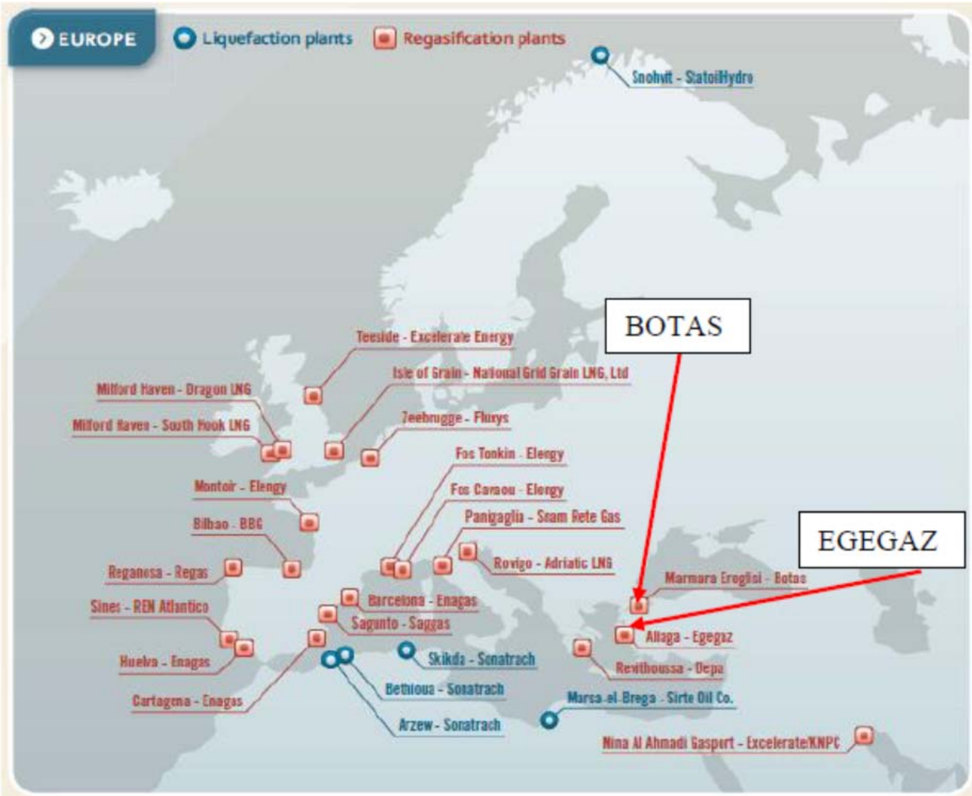

Figure 22. LNG Terminals of Europe (From [49])

The LNG imported from Algeria and Nigeria passes through the Canakkale Strait and goes to the Marmara Ereglisi LNG Terminal. There is no LNG terminal in north of the Sea of Marmara and in the Black Sea as of 2012 [50]. Therefore, there is no LNG traffic in the Istanbul Strait.

The Turkish Ministry of Transport, Maritime Affairs and Communications has statistics on the shipping traffic of the Turkish Straits. The tanker traffic is busy. Tankers are divided into 4 groups in the statistics: Crude oil tankers (TTA), Chemical tankers (TCH), LNG carriers (LNG), and LPG carriers (LPG) [19].

Istanbul Strait				
Years	Total	Tankers		
		TTA	LPG	TCH
2000	48,079	4,937	474	682
2001	42,637	5,188	546	782
2002	47,283	6,022	545	860
2003	46,939	6,571	598	928
2004	54,564	7,470	634	1,295
2005	54,794	7,577	681	1,769
2006	54,880	7,659	814	1,680
2007	56,606	7,204	800	2,050
2008	54,396	6,564	764	1,975
2009	51,422	6,557	866	1,876
2010	50,871	6,463	1,100	1,711
2011	49,798	6,229	1,227	1,647

Table 8. Tanker Statistics of Istanbul Strait (After [19])

Canakkale Strait					
Years	Total	Tankers			
		TTA	LPG	LNG	TCH
2000	41,561	5,543	607	65	1,184
2001	39,249	5,168	605	68	1,087
2002	42,669	5,650	589	66	1,190
2003	42,648	6,075	651	66	1,192
2004	48,421	7,061	764	58	1,133
2005	49,077	6,564	691	61	1,497
2006	48,915	7,204	733	65	1,447
2007	49,913	6,527	696	58	1,990
2008	48,978	5,990	721	56	1,991
2009	49,453	6,293	786	56	2,432
2010	46,686	6,017	844	58	2,333
2011	45,379	5,661	907	67	2,183

Table 9. Tanker Statistics of Canakkale Strait (After [19, 50])

B. LNG

Natural gas is a fossil fuel like coal and crude oil. It is cooled to a temperature of approximately -256^{o}F (-160^{o}C) to turn it into liquid form. In this liquefaction process, the volume of the natural gas is reduced approximately 600 times. This liquid form is called LNG, which is more proper to store and transport. LNG is mostly (95%) methane (CH_4), and odorless, colorless, flammable, non-toxic and non-corrosive [51].

LNG has been transported by ship for more than 50 years. "In January 1959, the world's first LNG tanker, The Methane Pioneer, a converted World War II liberty freighter containing five, 7000 barrel equivalent aluminum prismatic tanks with balsa wood supports and insulation of plywood and urethane, carried an LNG cargo from Lake Charles, Louisiana to Canvey Island, United Kingdom. This event demonstrated that large quantities of liquefied natural gas could be transported safely across the ocean" [51]. Today, there are nearly 400 carriers in the world LNG fleet [52].

Figure 23. A Typical Moss-sphere-designed LNG ship (From [53])

LNG carrier ships have a double-hulled design to increase safety. A typical modern LNG carrier is about 300 m. long, 43 m. wide and 12 m. deep. LNG carriers have a cruising speed of 21 knots, and their cargo capacities vary from 1,000 to 267,000 cubic meters [54].

1. Hazards and Risks

LNG is not stored under pressure; therefore there is no risk of explosion caused by pressure. On the other hand, released LNG vapors are flammable and can become explosive under certain conditions. The flammability range depends on the mixture of air and LNG vapors. Vapors can be ignited if diluted 5 to 15% by volume in air. Visible vapor clouds are formed after the release of LNG. This flammable mixture can be ignited from sparks, flames or can spontaneously ignite if the conditions are right. This is called auto-ignition. Because the auto-ignition temperature is above 1000^{o}F (540^{o}C) for LNG, the risk of auto-ignition is very low, but is still a concern [55].

LNG explosions can be separated into two types with respect to the method and time of ignition.

a. Immediate Ignition

A terrorist attack on an LNG carrier ship with explosives, missiles or vehicles (aircraft and ship) will cause an immediate ignition and then a flash fire. This will produce a pool of fire, which has an effect on a limited area near the ship [56].

b. Ignition after Release

LNG can be released by the terrorists without use of weapons. This may cause LNG vapor clouds to move to public areas before exploding. After vaporization and being mixed in the right proportions with the air, LNG can be easily ignited.

> The measured minimum ignition energy of LNG vapors is 0.29 mJ (milli-Joules). Flammable LNG vapors are easily ignited by machinery, cigarettes, and static electricity. Static electricity discharged when one walks on a carpet or brushes his/her hair is 10 mJ, or 35 times the amount required to ignite LNG vapors. A large LNG vapor cloud cannot travel far into developed areas without igniting and burning back to the source. [56]

This is not the case for undeveloped areas. There are three well known accidents in which there were no ignitions after the release. Approximately 1,500 to 2,000 cubic meters of LNG were released from the Camel plant, Algeria, in 1977.

However, the resulting vapor cloud did not ignite. Released LNG vapors also did not ignite in accidents at Das Island, United Arab Emirates, in 1978 and Bontang, Indonesia, in 1993 [57].

Based on the above explanations, a terrorist organization most probably would choose the ignition after release option because of its catastrophic explosion.

Melhem et al. [56] report that the major injuries and significant damage to property resulting from an intentional LNG breach extends no more than one half mile from the spill origin.

2. Safety Requirements for LNG

a. Primary Containment

The most important safety requirement is adequate primary containment. Using proper materials and engineering designs for primary storage tanks is the only way to provide this safety.

b. Secondary Containment

If LNG should leak or spill from the primary storage tank, a secondary containment layer will keep the LNG safely isolated from the environment.

c. Safeguard Systems

As in other dangerous material industries, safeguards can detect leaks or fire and shut off systems when there is a breach in the containment system. These have a great role in LNG safety.

d. Separation Distance

LNG facilities must be sited away from other facilities or public areas. There must also be safety zones around LNG carrier ships. These safe distances and safety zones are stipulated by government regulations based on LNG vapor dispersion data, thermal radiation contours and other considerations [55].

In case of a terrorist attack on an LNG carrier ship, separation distance is the most important safety requirement to protect the public from the effects of explosion. If LNG is released, the vapor clouds may move to populated areas before exploding. This may cause a catastrophic loss of life in the Turkish Straits.

The narrow geographical conditions and the dense marine traffic of the straits do not allow the necessary safe distances or zones around LNG carrier ships.

3. LNG Accident History

There have been fewer than a hundred reported incidents (19 land-based LNG facilities, 31 LNG ships, and 22 LNG tanker truck) in the 70-year-old history of the LNG industry [57]. The three significant accidents are:

a. Cleveland, Ohio: 1944

During World War II, there was a shortage of stainless steel. In that period the East Ohio Gas Company expanded its facility by adding a larger tank. The stainless steel shortage caused compromises in the design of the new tank which failed after a short service. The released LNG formed vapor clouds in the neighborhood area and the storm-sewer system, and the vaporized gas in the storm-sewer system ignited. The explosion killed 128 people [55], [57].

b. Staten Island, New York: 1973

Operators in the Texas Eastern Transmission Company peakshaving facility detected tears causing leaks in an LNG tank. The tank was emptied; unfortunately, an ignition and a fire occurred during the repairs. This fire increased the tank pressure, causing an explosion that dislodged a 6-inch-thick concrete roof. This accident killed 40 people [55], [57].

c. Skikda, Algeria: 2004

A leak in a hydrocarbon refrigerant system formed a vapor cloud, an ignition occurred, followed by an explosion. The fire and more explosions destroyed part of the facility and killed 27 people and injured 72 more [57].

4. Maximum Impact Scenario for Immediate Ignition

Melhem et al. [58] assume a scenario in which a terrorist successfully creates a 1-meter-diameter hole in the center tank of an LNG carrier ship at the waterline. The carrier is berthed and fully loaded (200,000 cubic meters). They assume that the hole is created using an explosive charge delivered from a vehicle like a small aircraft, and then an immediate ignition occurs. The immediate ignition causes an unconfined pool fire.

According to this scenario, if simultaneous failure of three or four tanks occurs, approximately 150,000 cubic meters of LNG would be released in 5 minutes. A flame emissive power of 220 kW/m^2 extends to a distance of 3.7 km (the 50% fatality limit), excluding the contribution of solar flux. This fatality range shows that a terrorist attack on LNG carrier ships could cause catastrophic results in the Turkish Straits.

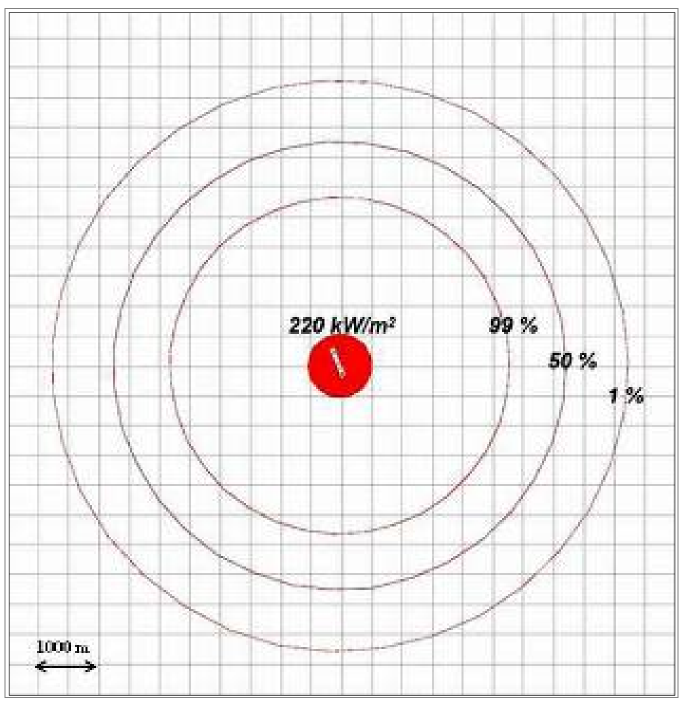

Figure 24. Thermal Radiation Hazard Zones in Percentage of Fatalities (After [58])

C. LPG

LPG is mainly propane (C_3H_8), butane (C_4H_{10}) or a mixture of propane and butane. "LPG is usually derived from fossil fuel sources, being manufactured during refining of crude oil, or extracted from oil or gas streams as they emerge from the ground" [59]. LPG is colorless, flammable, and it forms an explosive mixture with air.

There are three types of LPG carrier ships: fully refrigerated ships, semi-pressurized (semi-refrigerated) ships, and fully pressurized ships. The world's existing LPG fleet numbers 1,092 ships with 166 vessels on order as of May 1, 2010. Semi-pressurized gas carriers constitute the largest group with 532 vessels. This type of carrier has a capacity ranging from a few hundred to 10,000 cubic meters of LPG [60].

Figure 25. A Typical LPG Carrier Ship (From [61])

The Turkish Straits have a busy traffic of LPG carrier ships. Turkey has lots of LPG terminals around the Sea of Marmara due to the high need for energy of the country's most industrialized and populated region. There are also many LPG terminals in the Black Sea: Russia (Temryuk, Taman), Ukraine (Odessa, Illichivsk, Kerch), Georgia (Batumi), and Abkhazia (Sukhumi).

1. Types of LPG Explosions

Basically, there are two types of LPG explosion: a vapor cloud explosion (VCE) and a boiling liquid expanding vapor explosion (BLEVE).

a. VCE

A VCE is the most destructive type of explosion for chemical industries. The sequence of steps is the same as for the LNG vapor explosion analyzed in the previous section. First, a large quantity of flammable vapor suddenly releases, the vapor throughout the plant site disperses while mixing with air, and finally the vapor cloud ignites. The vapor cloud can be ignited if diluted between 2.1 to 9.5% by volume in air [55].

b. BLEVE

> If a vessel partly filled with liquid [but] with vapor above filling the remainder of the container, is ruptured -for example, due to corrosion, or failure under pressure- the vapor portion may rapidly leak, lowering the pressure inside the container. This sudden drop in pressure inside the container causes violent boiling of the liquid, which rapidly liberates large amounts of vapor. The pressure of this vapor can be extremely high, causing a significant wave of overpressure (an explosion) which may completely destroy the storage vessel and project fragments over the surrounding area. [62]

2. LPG Accident History

There have been several LPG accidents. One significant and one recent accident are presented in here:

a. San Juanico, Mexico City, Mexico, 1984

This is one of the deadliest disasters in industrial world history. A pipe rupture during LPG transfer caused a gas leak in the PEMEX LPG terminal in San Juanico. 10 minutes after the leakage, the gas vapor cloud ignited. Then a tank underwent a BLEVE. This explosion caused a chain of accidents or domino effect. Twelve separate BLEVEs occurred within an hour. Explosions propelled metal fragments up to 1,200 meters. 500 to 600 deaths and 5,000 to 7,000 severe injuries were reported after the explosions [63].

b. Viareggio, Italy, 2009

As Brambilla et al. summarize:

> A freight train carrying LPG went off the rails and five out of fourteen wagons derailed and overturned. A hole formed in the first tank car due to the impact with a signaling stake. The pressurized LPG was released as a two-phase jet: the liquid phase formed a boiling pool on the ballast while the dense gas dispersed in the atmosphere. The dense cloud spread and moved towards the neighboring houses. Afterwards, the cloud was ignited and exploded. The overpressure destroyed some residential buildings in the area closest to the explosion epicenter, while glasses were shattered in a larger area. Thirty-one people died and a number of residents were injured due to the fires that engulfed the surrounding houses.” [64]

Each tank was loaded with 45 tons of LPG. After the first release of LPG from the tank, the vapor cloud moved for 2 to 5 minutes before the explosion. [64]

3. Conclusion

In the Viareggio accident, a tank with the capacity of 45 tons of LPG killed 31 people in the neighboring area. An average LPG carrier ship has a cargo of thousands of tons of LPG. An explosion in such a carrier passing through the Turkish Straits may cause the death of thousands of people. Therefore, LPG carriers are high value targets for maritime terrorism.

D. OTHER DANGEROUS CHEMICAL CARGO

Other than LNG and LPG there are different types of dangerous chemical cargo transported through the Turkish Straits. Some of these chemicals have relatively greater shipping statistics, such as ethylene (C_2H_4), ammonia (NH_3), ammonium nitrate (NH_4NO_3), and propylene (C_3H_6). The most dangerous of these chemicals are ammonium nitrate and ethylene [65].

1. Ammonium Nitrate

Ammonium nitrate is a highly explosive chemical [65]. There have been 3 significant ship accidents involving NH_4NO_3 and in all the accidents the ships exploded and sank. The first one was the cargo ship Grandcamp accident in Texas City, US, in

1947. The ship was loaded with 2,600 tons of ammonium nitrate. A fire was detected, and an hour later the ship exploded, killing several hundred people. The explosion caused fire to another vessel, the High Flyer, moored 250 meters away. This ship also had 960 tons of ammonium nitrate, and subsequently exploded [66].

In 1947, the cargo ship Ocean Liberty exploded because of a fire. The ship was loaded with 3,300 tons of ammonium nitrate. 29 people died and the port of Brest, France, was seriously damaged [66].

In 1954 the cargo ship Tirrenia exploded in the Red Sea, the explosion caused by fire like the previous accidents. The ship was abandoned before the explosion; therefore, nobody died [66].

Other than the ships, there have been more than 20 land-based accidents. One of them is presented here as an example. A fire caused the explosion of 23 tons of ammonium nitrate in Kansas City, Missouri in November 1988. There were 2 blasts, creating two craters 30 meters (100 feet) wide and 2.4 meters (8 feet) deep. Residential windows in a 16 km (10 miles) range were shattered, and the explosions could be heard 64 km (40 miles) away [66].

In all these accidents, there was no immediate explosion after the fire. Therefore, in case of a fire, there is a chance to prevent the explosion. However, if the fire is not extinguished, the results can be catastrophic.

2. Ethylene

Ethylene is extremely flammable. LPG ships may also carry ethylene. Therefore ethylene carriers are considered as a part of the LPG fleet. Figure 26 illustrates the number of fully refrigerated, ethylene, semi-refrigerated, and fully pressurized ships of the world [60]. Ethylene carriers are fully refrigerated ships which have a double-bottomed design.

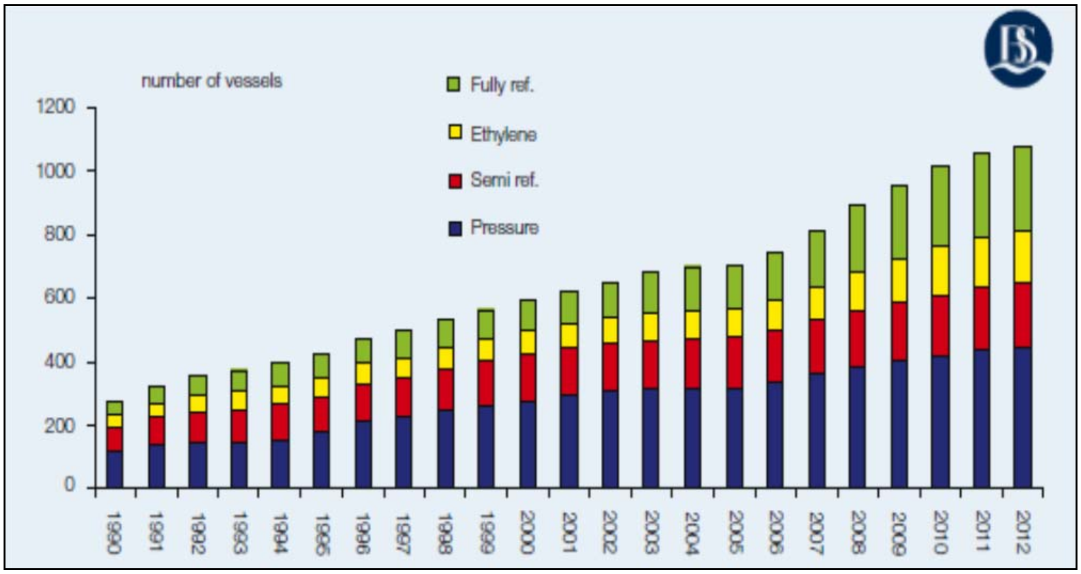

Figure 26. World's LPG and Ethylene Fleet (From [60])

3. Conclusion

Based on the above information, like LNG and LPG cargo, dangerous chemicals transported through the Turkish Straits are also high-value targets for maritime terrorism. An explosion in such a carrier passing through the Turkish Straits may cause the death of thousands of people.

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V. DETERMINING THE MOST PROBABLE SCENARIO

This chapter seeks to answer three questions about maritime terrorism in the Turkish Straits:

- Which strait is the most probable location of a terrorist attack: Istanbul or Canakkale?
- Which type of ship has the highest value for a terrorist attack: LNG, LPG or other flammable/explosive cargo carriers?
- Which method will probably be used by terrorists: hijacking, shoulder-fired missiles, small aircraft, or other methods?

A. SELECTION OF STRAIT

Executing a successful maritime terrorism attack in the straits may create catastrophic results, including:

- Loss of thousands of lives,
- An economic crisis,
- Closure of the straits to navigation,
- An environmental catastrophe.

The Istanbul Strait divides the city of Istanbul, the most crowded city of Turkey, in half. There were 13,624,240 people living in Istanbul at the end of 2011 (18.2% of Turkey's population) [2]. The population is very dense around the strait. Istanbul is the economic center of Turkey. The city produces 27% of the gross national domestic product (GDP) and 38% of total industrial output [12].

Similar to Istanbul, the city of Canakkale is located beside a strait, the Canakkale Strait. The total population of the city was 486,445 people at the end of 2011, and the population around the strait was just under 200,000 people [17]. The economy depends on the agriculture and fishing industries.

Based on the above information, the Istanbul Strait would probably be the first choice of a terrorist organization executing a maritime terrorism attack. Istanbul is the heart of Turkey.

B. SELECTION OF SHIP TYPE

There is a dense traffic of hazardous/dangerous cargo ships in the Turkish Straits. Some of these cargos have flammable/explosive physical properties. An explosion of one of these ships would obviously increase the damaging effects of the terrorist attack because of its cargo. These ships are high-value targets. As mentioned before, these ships carry LPG, crude oil and oil products between the Black Sea littoral countries and Turkey, Europe, North Africa and the Americas; they carry LNG from Algeria and Nigeria to Turkey. Other flammable/explosive chemical materials like ethylene, propylene, and ammonium nitrate are also transported through the straits.

LNG is flammable, and it forms an explosive mixture with air. According to the worst case scenario of Melhem et al. [58], in case of simultaneous failure of three or four tanks of an LNG carrier ship after a terrorist attack, approximately 150,000 cubic meters of LNG would be released within 5 minutes. A flame emissive power of 220 kW/m^2 extends to a distance of 3.7 km (the 50% fatality limit), excluding the contribution of solar flux. This fatality range shows that a terrorist attack on LNG carrier ships could cause catastrophic results in the Turkish Straits, especially in crowded Istanbul.

There are two LNG terminals in Turkey. One of them is on the coast of the Sea of Marmara (BOTAS-Marmara Ereglisi LNG Terminal), and the other is on the Aegean Sea coast (EGEGAZ-Aliaga LNG Terminal) [49]. No LNG terminal is in the north of the Sea of Marmara, nor in the Black Sea as of the year 2012. Therefore, there is no LNG traffic in the Istanbul Strait currently. In future, Ukraine and other Black Sea countries may build LNG terminals in the Black Sea to import cheaper LNG from Algeria, Nigeria or other countries [67].

A typical LNG ship's cargo is 10 to 15 times greater than a typical LPG ship's cargo, so the damaging effect of an LNG carrier ship explosion is much greater than that of a LPG carrier. On the other hand, an attack on an LNG carrier ship can only be executed in the Canakkale Strait as of today. Therefore, LNG carrier ships are not assumed targets of first choice by a terrorist organization.

The most dangerous chemicals transported through the straits are ammonium nitrate and ethylene. Ammonium nitrate is a highly explosive chemical, and ethylene is extremely flammable [65]. There are few scientific reports about the dangers of ammonium nitrate and ethylene (fatality range, etc.) as opposed to LNG and LPG, and there are no accessible shipping statistical reports about these materials. Based on reports about the previous accidents, no immediate explosion follows the fire [66]. Therefore, in case of a fire, there is a chance to prevent the explosion. Because of the limited public information about these chemicals and a comparatively high possibility of extinguishing the fire, a terrorist organization may not choose to attack these ships.

LPG is flammable, and it forms an explosive mixture with air. The Turkish Straits host a large traffic of LPG carrier ships. We know that in the Viareggio accident, an LPG tank with capacity of 45 tons caused the deaths of 31 people in a neighborhood area [64]. An average LPG carrier ship has a cargo of thousands of tons of LPG. An explosion in such a carrier passing through the Turkish Straits may cause the death of thousands of people. As mentioned before, there are 2 types of LPG explosion: a vapor cloud explosion (VCE) and a boiling liquid expanding vapor explosion (BLEVE). If a terrorist organization prefers the VCE, the ship can explode before passing the busiest part of the strait because of the unpredictable explosion time of the VCE. Therefore, terrorists probably would choose the BLEVE.

Many works about LPG accidents in history exist, and it is easy to access LPG shipping statistics. There are many LPG terminals in Turkey and the Black Sea littoral countries. Terrorist organizations can access the fatality range, shipping traffic statistics, and export/import terminal information about LPG.

Based on the above information LPG carrier ships will probably be the first choice of a terrorist organization executing a maritime terrorism attack.

C. SELECTION OF METHOD OF ATTACK

As decided, the most dangerous scenario for the Turkish Straits is explosion of an LPG carrier ship during its passage of the Istanbul Strait. There are several applicable methods to realize this maritime terrorism. Before analyzing these methods separately, two of the factors that affect the decision process of terrorist organizations about methods of attack are explained. These factors are the Black Sea Naval Cooperation Task Group (BLACKSEAFOR) and the Automatic Identification System (AIS).

1. Black Sea Naval Cooperation Task Group

The BLACKSEAFOR is a multinational (the Black Sea littoral states of Turkey, Russia, Romania, Ukraine, Bulgaria, and Georgia) on-call naval peace task force. The task force is composed of a minimum of 4 to 6 ships from the member countries. The main ship types are frigate/destroyer, corvette/patrol boat, mine counter-measures ship, amphibious ship and auxiliary ship. [68]

The BLACKSEAFOR was established at the initiation of Turkey for the purpose of enhancing peace and stability in the Black Sea area. After the 11th of September terrorist attacks on the World Trade Center Towers in New York, the BLACKSEAFOR transformed its purposes. “The main purposes of transformation of BLACKSEAFOR are;

- To activate BLACKSEAFOR two times in a year to conduct unscheduled activations and to conduct training programs in areas including preventing the threat of terrorism and eliminating illicit trafficking in weapons of mass destruction, their means of delivery and related materials,
- To change BLACKSEAFOR with the constabulary mission including struggling with global terror,
- To have a permanent command center on a rotational basis,
- To have an information exchange system amongst Black Sea littorals.” [68]

2. Automatic Identification System (AIS)

AIS transponders automatically provide a ship’s information (identity, type, position, course, speed, navigational status and other safety-related information) to other ships and to coastal stations [69]. In 2000, the International Maritime Organization (IMO) created a new requirement. According to this requirement, International Convention for the Safety of Life at Sea (SOLAS) Regulation 19, Chapter V, most ships must carry AIS transponders on board.

> The regulation requires AIS to be fitted aboard all ships of 300 gross tonnages and upwards engaged on international voyages, cargo ships of 500 gross tonnages and upwards not engaged on international voyages and all passenger ships irrespective of size. The requirement became effective for all ships by 31 December 2004. [70]

AIS information is easily accessible on the internet. Figure 27 shows an example of the maritime traffic of the Istanbul Strait at 14.22 pm on 18 January 2012. Detailed information about selected ships (by user) is also available [71].

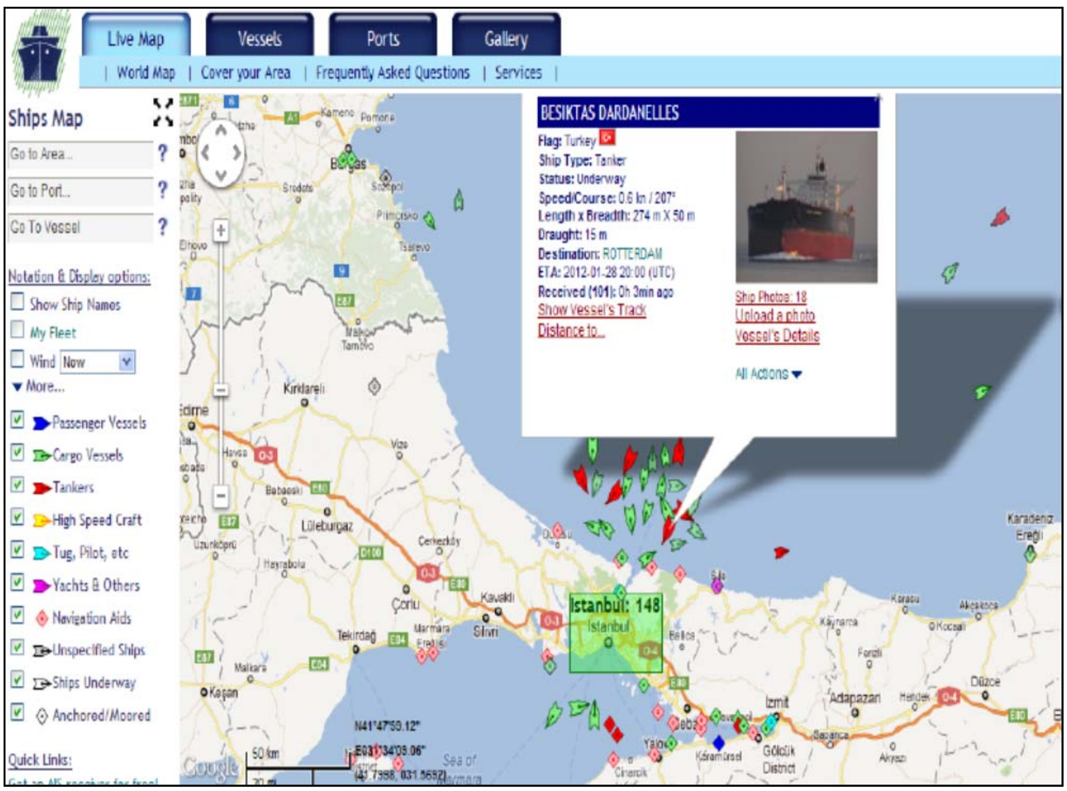

Figure 27. Accessible AIS Information on Internet (From [71])

3. Analysis of the Methods

These are the possible ways to execute a terrorist attack on an LPG carrier ship in the Istanbul Strait:

a. Small Boat Attack (Unmanned or Suicide Attack)

There is both international (about 50,000 ships pass yearly [18], [19]) and local (up to 2,500 vessels daily [72]) ship traffic in the Istanbul Strait. This traffic density increases the risk of a small boat attack. Terrorists could conduct this type of attack with explosive-loaded small boats, both remotely operated (unmanned) and crewed (suicide attack) small boats. Currently there are some measures to prevent a small boat attack in the straits.

Turkey announced Maritime Traffic Regulations for the Turkish Straits in 1998. Article 26 of this regulation requires that "Vessels carrying dangerous and/or hazardous cargo or wastes, at least 72 hours before fixing a voyage through the straits, must contact with the administration and inform the type of cargo planned to carry with all necessary certificates" [73]. In this way, Turkey is able to take safety and security measures. These ships are observed before entering the strait and during their passages by land stations.

There are two methods of observation. AIS provides information about the current positions, courses and maritime traffic around these ships. The BLACKSEAFOR task group and the land-based radars of the member countries also may provide information about dangerous cargo carrier ships.

During the passages of these type ships, Turkey has a right to stop other marine traffic of the strait. For example, Canakkale Strait was closed to maritime traffic during the passage of the 289-meter-long LNG ship Adamawa in November 2011 [74]. In general, this limitation is not applied to local traffic.

Based on the above information, a small boat can be detected before hitting an LPG carrier. However, these boats are generally fast, and there might not be enough time to prevent the attack. The only foolproof way to prevent this type of attack is to escort all dangerous cargo carriers during their passage. The Turkish Coast Guard escorts all LNG, LPG, and other dangerous cargo carriers during their passage in the straits. Because of this measure, a small boat attack probably will not be the first choice for a method of attack by a terrorist organization.

b. Small Aircraft Attack (Unmanned or Suicide Attack)

Terrorists can use explosive-loaded small aircraft in the same manner as small boats. Both remotely operated (unmanned) and crewed (suicide attack) small aircraft can be used. Controlling the air traffic above the city of Istanbul is the only way to prevent this type of attack.

The purpose of this research is to improve the capabilities of the Turkish Navy and Coast Guard Commands against the maritime terrorism. As preventing aircraft attacks is not among the main missions of these commands, this method is not analyzed.

c. Small Underwater Vehicle Attack (Unmanned or Suicide Attack)

Terrorists can also use explosive-loaded underwater vehicles both remotely operated (unmanned) and crewed (suicide attack). Acoustic sensors (like hydrophones and sonar devices) are a useful way to detect underwater vehicles and prevent such an attack. For the terrorist to execute such an attack requires a high level of secrecy, technical knowledge, and craft experience. Because of its difficulty level, this method probably would not be the first choice of a terrorist organization.

d. Mines and Controlled Bombs

Terrorists can place mines and controlled bombs that can be activated during the cruise of the ship. Because of the difficulty level, this method probably would not be the first choice of a terrorist organization.

e. Shoulder-Fired Missile Attack

The Istanbul Strait has an average width of 0.81 NM, and a minimum width of 0.38 NM [7], [8]. Therefore, a standoff missile attack is a serious security problem for the strait. There are regulations governing the hull types of hazardous/dangerous cargo tankers. As an example, all tankers built after 1994 must have double hulls to enter U.S. ports [31]. The double hull type of construction of the ships may prevent explosion of the cargo and sinking of the tanker. Therefore, the results of a standoff missile attack may be limited, so this may force the terrorists to change the method of attack. Because the possibility of the ship exploding after a shoulder-fired missile attack is low, this method would not be the first choice of a terrorist organization.

f. Hijacking

The shipping route of oil and gas products is from the Black Sea to the Mediterranean Sea. Terrorists could use small boats to board and guns to take control of the tanker in the Black Sea. After the hijacked tanker entered the strait, terrorists would have two options: collision or explosion. The crew of the hijacked ship may inform authorities, and AIS and/or BLACKSEAFOR may detect hijacking. If the hijacked ship is away from the straits, the BLACKSEAFOR task group, Turkish Navy or Turkish Coast Guard Command could execute an operation to take control of the ship from the terrorists. In the worst case scenario, these forces could sink the hijacked ship before it entered the Istanbul Strait. In conclusion, the method of hijacking probably would not be the first choice of a terrorist organization.

g. Crew Conspiracy

Some of the crew could be members of a terrorist organization. In this way, terrorists do not have to execute a boarding operation, and the probability of being detected is minimized. These terrorist crew members may take control of the ship just before entering the Istanbul Strait. Similar to the hijacking scenario, after the tanker entered the strait, terrorists would have two options: collision or explosion. This method limits the actions of the Navy and Coast Guard in preventing the destruction of the hijacked LPG carrier ship. Based on the above information, crew conspiracy would probably be the first choice of a terrorist organization in executing a maritime terrorism attack.

D. THE FINAL SCENARIO

According to the results of this analysis, the easiest and the most effective demonstration of maritime terrorism is exploding an LPG carrier ship during its voyage through the Istanbul Strait by the method of crew conspiracy. The summary of the results:

- Selected strait: Istanbul Strait
- Selected ship type: LPG carrier
- Selected method of attack: Crew conspiracy

A sample ship for this scenario is to be selected before analyzing the protection methods in the next chapter.

1. Selection of the Sample Ship

The main purpose of this research is to design an applicable underwater system to improve the capabilities of protection against maritime terrorism. Therefore, the selection process of the sample ship must be realistic. There are three factors which must be considered.

First, a currently existing ship must be selected. The ship must actually voyage through the Istanbul Strait in real life. AIS has real-time marine traffic information, and there are lots of online web sites which have marine traffic information based on the AIS. An LPG carrier can be selected randomly by using these web sites after checking the cargo, departure and arrival-port history, and current position information. However, the randomly selected ship must meet some other requirements to be selected by a terrorist organization.

The second factor is the size of the ship. Turkey has a right to stop other marine traffic in the strait during the passage of hazardous cargo ships. Currently, this right is applied only to large vessels. Accordingly, these ships can be easily observed and escorted by the authorities during their passages. Therefore, from the point of view of a terrorist organization, it is better to select a relatively small LPG carrier.

The world's LPG fleet has more than 1,000 ships which have a capacity ranging from a few hundred to 85,000 cubic-meters of LPG [60], [75]. The average capacity of LPG carriers that voyage between Mediterranean ports is 11,291 deadweight tons (DWT), and the average capacity of the Mediterranean transits is 30,037 DWT [76]. The selected ship must be smaller than these ships.

The type of the LPG carrier ship has an effect on its size. Semi-pressurized/semi-refrigerated LPG carriers are the largest group, numbering 532 vessels of the more than 1000 ships of the world's LPG fleet. This type of ship has a capacity ranging from a few hundred to 10,000 cubic-meters of LPG [60], [75]. This is a relatively low capacity when compared with the 85,000 cubic-meters of the largest ships. Therefore, the sample ship might well be selected from this most-crowded type of LPG carriers, based on their smaller sizes and high numbers.

The third factor is a combination of ownership, crew, and route of the ships. Some LPG carrier ships only cruise on constant routes. If an LPG company with storage and processing facilities has its own fleet and long-term contracts, most probably they will use their own ships on constant routes. Therefore, a crew member will have better knowledge of the ship, the cargo, the other crew members, and the LPG cargo terminals. In this case, a crew conspiracy is less likely.

On the other hand, if the ship is owned by an LPG shipping company, then it can be rented by different LPG storage and processing companies and it may cruise between different ports based on the trade routes of the companies. From the point of view of a terrorist organization, it is better to select an LPG carrier that is owned by an LPG shipping company and that cruises between different ports.

Finally, based on these factors a group of LPG carriers were analyzed using the information provided by online web sites [71], [77], [78]. The LPG carrier ship Syn Mira (IMO 8705723) was selected as the sample ship. The Syn Mira (sample ship) is a semi-pressurized/semi-refrigerated LPG carrier ship owned by an LPG shipping company [79].

The sample ship does not voyage on constant routes as seen in this (Table 10) list of the ports visited by the ship.

Port History of the Sample Ship	
Date	**Port/Country**
27-Jan-2012	Nador/Morocco
27-Oct-2011	Kerch/Ukraine
13-Oct-2011	Aliaga/Turkey
10-Oct-2011	Istanbul/Turkey
13-Sep-2011	Augusta/Italy
1-Sep-2011	Omisalj/Croatia
31-Aug-2011	Ravenna/Italy
31-Aug-2011	Omisalj/Croatia
27-Aug-2011	Piraeus/Italy

Table 10. Port History of the Sample Ship (From [77])

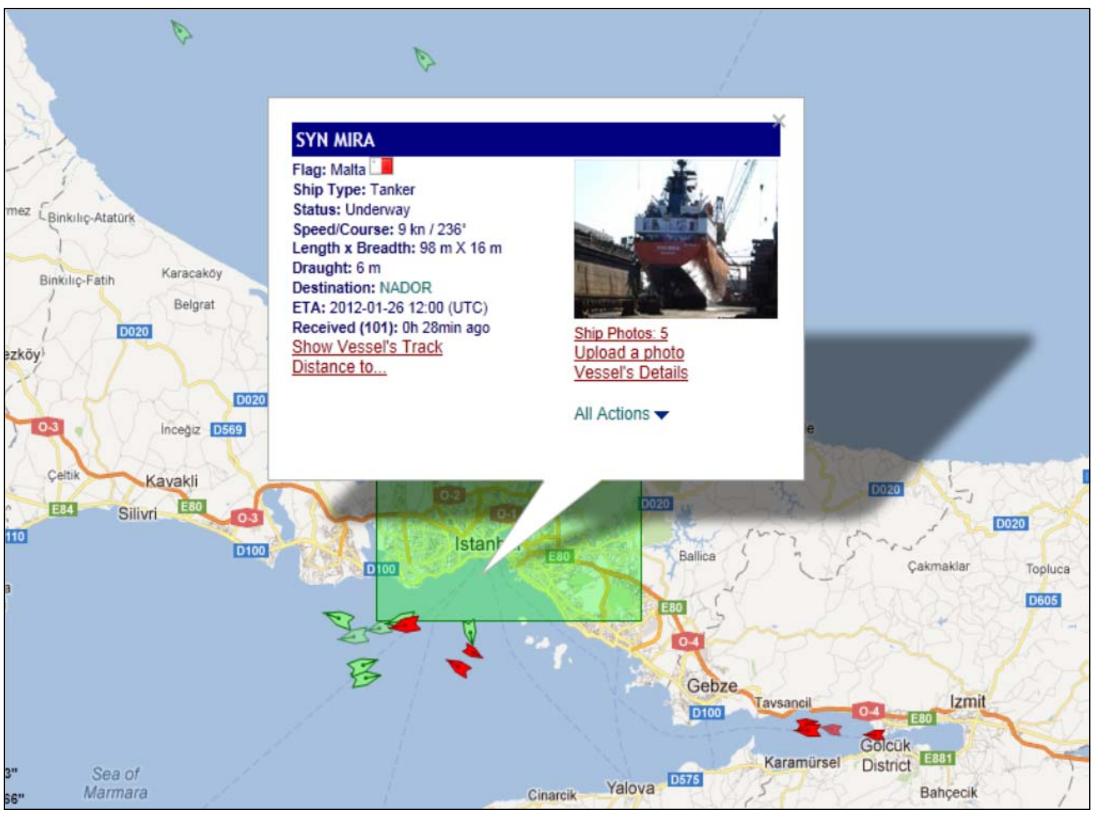

Figure 28. AIS - Voyage of the Sample Ship through the Istanbul Strait (From [71])

Figure 29. Sample Ship (From [80])

Characteristics of the Sample Ship	
LOA	97.5 m
LBP	90.0 m
Breadth	14.8 m
Draught	6.7 m
DWT	4,283 MT
Light displacement	2,784 MT
Loaded displacement	7,027 MT
Main engine power	3,088 Kw
Shaft generator	1,200 Kw
Maximum speed recorded by AIS	10.5 knots
Average speed recorded by AIS	9.1 knots

Table 11. Characteristics of the Sample Ship (From [79], [81])

2. Summary of the Scenario

Based on analysis and assumptions, the most probable method of maritime terrorism is the explosion of the sample ship during its passage through the Istanbul Strait. It is assumed that the terrorists will use crew conspiracy to execute this attack and they will keep the ship in the traffic lane before and during the passage. In this way, protective actions of the Navy and Coast Guard will be minimized. The purpose of this research is to design a system for protecting the Istanbul Strait against this scenario.

Methods of protection against this scenario will be analyzed in the next chapter. Before the analysis, the route of the sample ship must be determined. The sample ship has an average speed of 9.1 knots [81]. There is a north-to-south surface current in the strait with a speed of up to 4 knots, and peak current speed may reach 7–8 knots in narrow sections [7], [9]. Therefore, it is easy to navigate from north-to-south. The average current at the northern entrance of the Istanbul Strait is 1 knot [15]. Also, it is easier to stop a ship which cruises from south-to-north. Because, in this research, the most probable worst-case scenario is considered, it is assumed that the ship is cruising from north-to-south, the same direction as the surface current.

The southern part of the strait has a higher population density, so the damaging effects of an explosion in the southern part will be greater. Therefore, the terrorists will wait until the ship arrives in that portion of the strait. Finally, it is assumed that the sample ship is cruising from north to south and the terrorists plan to create the explosion in the southern part of the strait.

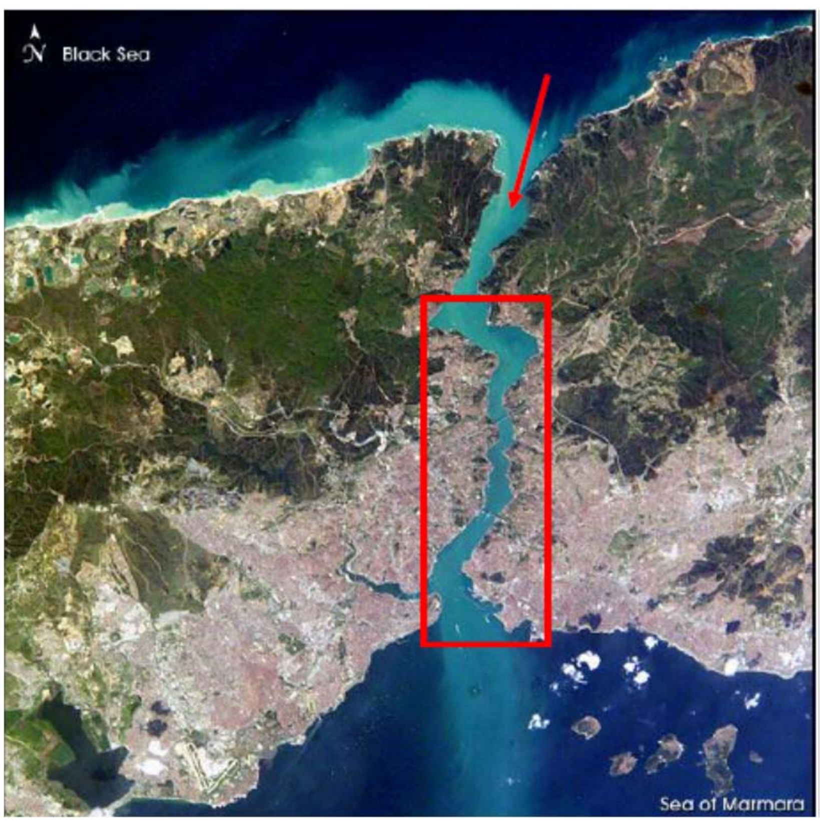

Figure 30. Assumed Direction of Cruise and Area of Attack (After [82])

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VI. PROTECTION AGAINST THE MOST PROBABLE SCENARIO

There are many advanced methods for protection against maritime terrorism. However, if authorities do not have enough time to apply these methods, there will be no protection. The only way to solve this problem is to receive intelligence as early as possible. If the terrorists take control of the sample ship and then cruise to the southern part of the Istanbul Strait without being detected, there is no possibility of preventing the explosion; the terrorists will successfully execute this attack. Even if authorities have many different methods of defense, there is no way to apply these methods without intelligence. As mentioned before, the purpose of this research is to design a new system to improve the capabilities of protection against maritime terrorism once it has been recognized. Therefore, it is assumed that the authorities have intelligence about the terrorists in the sample ship.

First, existing protection methods were analyzed based on the most probable scenario. This analysis, determined whether the currently available capabilities are enough to stop the sample ship. Then, a new system was designed to improve the capabilities of protection by analyzing the not yet extant methods.

A. EXISTING METHODS FOR STOPPING THE SAMPLE SHIP

The existing methods are divided into two groups:

- Methods for preventing a terrorist attack on a target ship,
- Methods for taking control of the ship from the terrorists.

1. Analysis of the Existing Methods for Preventing a Terrorist Attack on a Target Ship

The terrorists eliminated all existing methods for preventing a terrorist attack on a target ship by using the crew-conspiracy method. Other than these, the methods which have size limitations (barriers, stopping the propeller of a small boat) are also inapplicable in this scenario because of the length (97.5 meters), and the displacement (7,027 MT) of the sample ship.

Therefore, there is no need to analyze these methods. The summary of the inapplicable methods for this scenario:

Inapplicable - Existing Methods for Preventing a Terrorist Attack on a Target Ship for the Most Probable Scenario	**Protection**	
	Yes	**No**
Escorting Ships While Cruising In Critical Waters	-	X
Patrolling around Important Maritime Platforms and Shore Facilities	-	X
Using Non-Lethal Weapons	-	X
Stopping the Propeller of a Small Boat	-	X
Using Scanning Devices for Finding the Terrorists and Bombs	-	X
Applying Early Detection Systems	-	X
Having Security Teams on Board of Commercial Ships	-	X
Using Barriers	-	X

Table 12. Existing Methods for Preventing a Terrorist Attack on a Target Ship

2. Analysis of the Applicable - Existing Methods for Taking Control of the Ship from the Terrorists for the Most Probable Scenario

a. Boarding

The Coast Guard and Navy have special boarding teams that can execute an operation to take control of the ship from terrorists. On the other hand, there are two other possibilities. First, the boarding operation may be unsuccessful, and the sample ship may enter the strait. Second, it may be too late for the teams to board the sample ship when intelligence arrives. If the sample ship is very close to the entrance of the strait, there may not be enough time for boarding. In conclusion, information must be timely acquired, and the boarding must be successfully executed.

If boarding is unsuccessful, there might not be enough time for a second operation, or if information about the plot is late and the sample ship is already close to the entrance of the strait, there is currently no other way to stop the ship. The authorities must have alternative methods besides boarding. In the end, boarding may not be a guaranteed solution for this scenario.

b. Gunfire by Warships, Aircraft, or Land-Based Platforms

Gunfire can be used to shoot the sample ship, but this may cause an immediate LPG explosion, sinking of the ship and an environmental catastrophe. These results are acceptable compared with the death of thousands of innocent people in Istanbul. It is obvious, however, that the sample ship must be stopped or sunk before it enters the strait. To apply this method, there must be enough time to dispatch the closest or fastest warship, submarine or aircraft. Land-based artillery or missile stations also can be used.

As in the boarding method, this method can be applied if the ship is away from the straits. Otherwise, use of gunfire against the sample ship is not possible. Therefore, this method is not applicable if the sample ship is in the strait.

c. Tugboats

Using high-powered tugboats can be an effective solution to the light displacement of terrorist ships and boats. Tugboats may steer the course of the sample ship towards land and cause grounding of the ship before it enters the strait. Similar to the boarding and gunfire methods, if the ship is away from the straits, this method can be applied.

On the other hand, protective efforts of tugboats can be eliminated if the terrorists have skills enough to maneuver the sample ship. In this scenario of a crew conspiracy some of the terrorists may have the capability of navigating the ship.

3. Summary of the Existing Methods

These methods can be divided into three categories based on their protective functions in the scenario:

- Yes: Applicable in the scenario.

- Depends: Applicable only in specific conditions.
- No: Inapplicable in the scenario.

Existing Methods	Protection		
	Yes	Depends	No
Escorting the Ships While Cruising In Critical Waters	-	-	X
Patrolling around the Important Maritime Platforms and Shore Facilities	-	-	X
Using Non-Lethal Weapons	-	-	X
Stopping the Propeller of a Small Boat	-	-	X
Using Scanning Devices for Finding the Terrorists and Bombs	-	-	X
Early Detection Systems	-	-	X
Having Security Teams on Board of the Commercial Ships	-	-	X
Barriers	-	-	X
Boarding	-	X	-
Gunfire	-	X	-
Tugboats	-	X	-

Table 13. Summary of Existing Methods

Table 13 demonstrates that, currently, there is no absolute protection against the most probable scenario. The sample ship may cruise to the southern part of the strait to execute the terrorism attack. Therefore, a new system must be designed to improve protection by analyzing currently non-existent methods.

B. NON-EXISTENT METHODS FOR STOPPING THE SAMPLE SHIP

1. Analysis of the Non-Existent Methods

a. Stopping the Propeller

As mentioned before, currently there is no system for stopping a ship's propeller. Rope, wire, and/or nets can be wrapped around the ship's propeller. In this way, the propeller can be stopped or, at least, the thrust and propeller's efficiency can be reduced. Though the U.S. Coast Guard is using a system for stopping a small boat's propeller [41], this system has size limitations and is inapplicable for the sample ship. In the future, a method for stopping a ship's propeller can be a proper solution to the scenario. On the other hand, there are some products that can be installed between the propeller and the shaft to cut the ropes or lines wrapped around the propeller [83]. While these cutters are not commonly in use, their effects must be considered.

b. Damaging the Propeller

Currently, there is no system for damaging a ship's propeller. In the future, light-weight underwater weapons may be used to damage the propeller of the ship. Also the dangerous cargo of the sample ship makes this method not applicable in the strait. It can be applied out of the strait.

c. Impeding Steering by Damaging the Rudder

Currently, there is no system for impeding the steering of a terrorist ship. As in the case of the propeller, in the future, light-weight underwater weapons may be used to damage the rudder of the ship. The dangerous cargo of the sample ship renders this method not applicable in the strait. It can be applied out of the strait.

d. Stopping the Engines by Interrupting the Air Flow

Currently, there is no system for interrupting air flow to the engines. This method is more impractical or unfeasible than the other methods.

e. Restricting Visibility

Currently, there is no system to restrict the visibility of a terrorist ship. As well, this method is not applicable for the sample ship because terrorists can use the on-board radar displays to access navigation information. In the future, this method may prevent an attack by small boat, which has no navigational devices.

f. *Damaging all the Electronic Systems of the Ship by Non-Nuclear Electromagnetic Pulse (NNEMP)*

Although an NNEMP weapon may damage electronic systems of a ship, all ships have alternative systems for use in case of an emergency or malfunction. These alternate systems can control the engines and rudders of the ship, especially mechanical systems. Therefore, such systems will not be affected by an NNEMP attack. In the case of a crew conspiracy, the success of the NNEMP attack also depends on the nautical knowledge of the terrorists. Currently, there is no NNEMP weapon to damage the electronic systems of a terrorist ship.

g. *Changing the Course of the Ship by Underwater Explosions*

Changing the course of the terrorist ship may prevent a collision. This method is useful in protecting critical maritime platforms, harbor entrances, and shore facilities. However, it is inapplicable for the sample ship. The terrorists may simply correct the course of the ship and cruise toward the strait. Currently, there is no underwater explosion system to change the course of the terrorist ship and prevent collision.

h. *Clogging the Seawater Inlets of the Engine's Cooling System*

Clogging the seawater inlets will cause over-heating in the engines, so the engine will be stopped, but this may take some time after clogging. Currently, there is no system to clog the seawater inlets of the cooling system of a marine engine.

i. *Remotely Controlled Signals to Stop the Ship's Engines*

Almost all marine engines have electronic command and control systems. If a marine engine manufacturer has designed an engine that can be stopped by a remotely controlled signal, it will be easy to stop such a ship. These manufacturers sell the same engines for warships. No countries will accept having an engine that can be stopped by a remote signal. In the future, a remotely controlled system for stopping the engines of a merchant fleet for anti-terrorism purposes is possible, but as in the NNEMP case, ships may have spare mechanical systems to fall back on. Currently, there is no system for stopping an engine by remotely controlled signals.

2. Summary of the Non-Existent Methods

All the non-existent methods for stopping the sample ship were analyzed. The new design must be inspired by one of these methods. Two factors affect the selection of the new design. First, the method must be *applicable* and *provide protection* in the scenario. Second, it must be *technologically practical and feasible*.

Non-Existent Methods	Applicability in the Scenario			Technological Feasibility		
	Yes	Depends	No	High	Medium	Low
Stopping the Propeller	X	-	-	X	-	-
Damaging the Propeller	-	X	-	X	-	-
Damaging the Rudder	-	X	-	X	-	-
Interrupting Air Flow	X	-	-	-	-	X
Restricting Visibility	-	-	X	-	-	X
NNEMP	-	X	-	-	X	-
Underwater Explosions	-	-	X	X	-	-
Clogging the Seawater Inlets	X	-	-	-	-	X
Remotely Controlled Signals	-	X	-	-	X	-

Table 14. Summary of the Non-existent Methods

Based on these results, stopping the propeller is the most applicable and feasible method of stopping the ship. Therefore, the purpose of the new design is to stop the propeller of the sample ship.

C. STOPPING THE PROPELLER OF A TERRORIST SHIP

In real life, there are many examples of free ropes or nets wrapping around ships' propellers. Wrapping may stop the propeller by decreasing its efficiency and thrust.

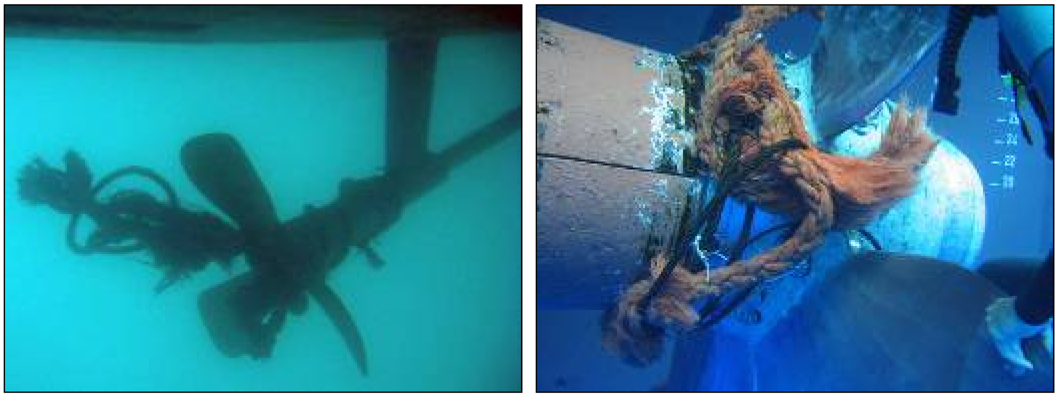

Figure 31. Examples of Ropes Wrapped around Propellers (From [84], [85])

Figure 32. Examples of Nets Wrapped around Propellers (From [40], [86])

There are cases in which this undesirable condition has been employed to great effect, such as by anti-whaling activists. In recent years, activists from the ships Sea Shepherd and Steve Irwin deployed ropes from zodiac boats to entangle the propellers of Japanese whaling vessels. This is not easy to execute. The ropes wrapped around the zodiac's own propeller in one of these attempts, in January, 2011 [87]. Figure 33 shows the rope entangled on the propeller of the Japanese whaling ship Yushin Maru No.3 [88].

Figure 33. Rope Entangled on the Propeller of Whaling Ship (From [88])

As mentioned before, there are two systems designed to stop the propeller of a small boat: the boat trap and the pirate trap. The U.S. Coast Guard is using a non-lethal system called “boat trap.” Ballistic nets are strategically dropped from a helicopter to wrap the propeller of a terrorist boat. The system stopped 100% of small boat targets in the tests [40].

The pirate trap—designed by the Royal Dutch Coast Guard, the Royal Dutch Navy, and the Royal Netherlands Sea Rescue Organization—carries thin lines around the ship, both sides and stern, suspended from booms. These thin lines float at the waterline. Whenever a small boat broaches this protected area, these lines wrap around the propeller and prevent the boat’s progress. [43]

Examples from real life and the applications of the “boat trap” and “pirate trap” demonstrate that ropes and nets can be wrapped around ships’ propellers by chance or on purpose. In this way, the propeller’s efficiency is decreased, and the ship is stopped. Therefore, wrapping the propeller will be the first objective of the design.

1. Types of Wrapping

The ropes or nets can be wrapped around two different parts of the ship’s propulsion system. The first part is located between the propeller and the ship’s hull:

stern tube, propeller shaft and propeller's hub (boss). The second part is the propeller blades. Figure 34 shows the typical view of a ship's parts that are located outside of the hull.

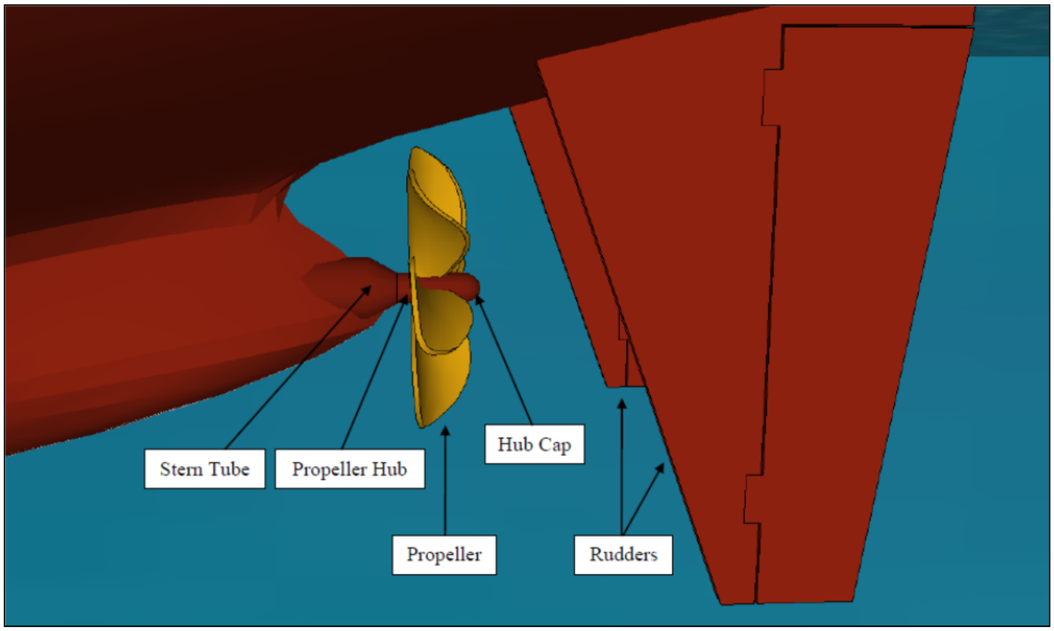

Figure 34. Parts of Propulsion and Rudder (After [89])

Figure 35. Sample Ship has 1 Propeller with 4 Blades (From [81])

a. Wrapping Around the Stern Tube/Shaft/Propeller's Hub

These parts are located between the propeller and the hull of the ship. Their location and dimensions depend on the choice of the designer. For example, a part of the propeller shaft may or may not be seen outside of the hull, depending on the design. If the whole shaft (outside of the hull) passes through the stern tube, then it is unseen.

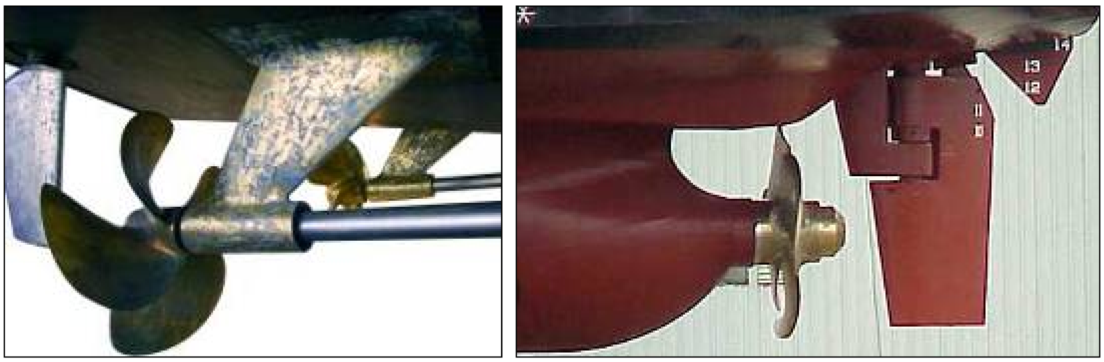

Figure 36. Different Types of Propulsion Design (From [90])

When wrapping occurs, the ropes or nets will roll up and accumulate towards the propeller's hub, located just behind the propeller blades, thereby increasing the diameter of the hub and decreasing the propeller's efficiency and its thrust. The ship will slow down, and stopping will be easier.

b. Wrapping Around the Propeller Blades

The ropes or nets can be wrapped around the propeller blades. For the calculations, it is assumed that the ropes or nets become part of the blades after wrapping, changing the blades' dimensions. Therefore, the blade areas and the thickness of the blades will be increased. Because of the difference in material properties, the roughness of the blades will also be increased. As well, the ropes or nets that are wrapped between the blades will increase resistance and change the characteristics of the flow around the blades. All these results of wrapping will negatively affect propeller efficiency. As with increasing the hub diameter, the thrust will be decreased, and finally, the ship will stop or slow down, and stopping the ship will be easier.

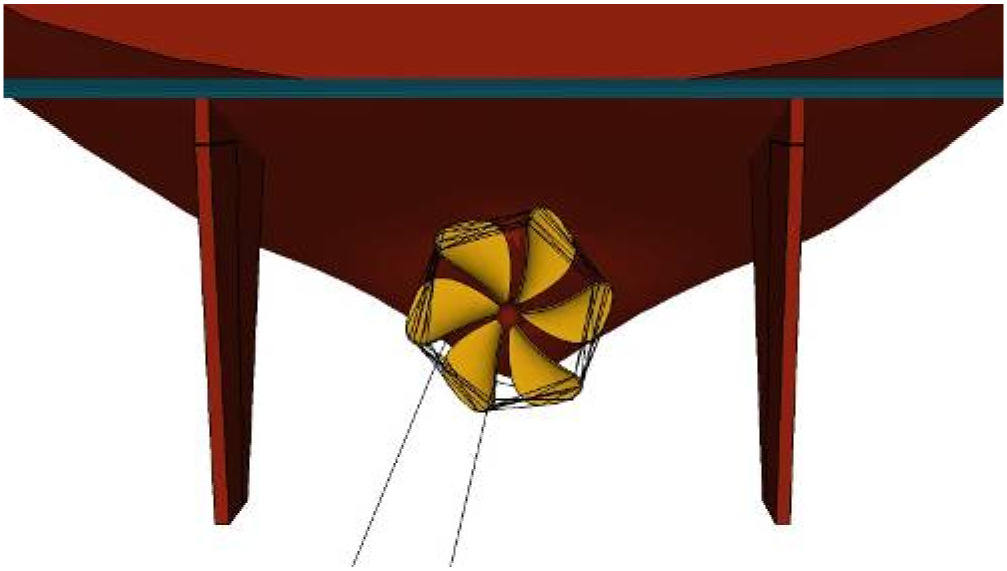

Figure 37. Wrapped Ropes around Propeller Blades (After [89])

2. Terminology and Equations of Ship Resistance and Propulsion

The ship propellers convert torque generated by the engines to thrust. To understand the relationship between a wrapped propeller or hub and the ship's speed, the terminology and equations of resistance/propulsion must be reviewed. Here is a list of the basic terms and equations related to ship resistance and propulsion [91], [92].

R_T: Total resistance (frictional + wave making + eddy/form + appendage + air)

T: Thrust

Q: Torque

n: Revolutions per second of shaft/propeller

V: Speed

V_A: Speed of advance

P_E: Effective power: power to overcome total resistance (R_T) at a ship speed (V)

EHP: Effective horse power

P_E = Total resistance x speed = $R_T \, x \, V$

P_T: Useful power output of the propeller (thrust power developed by propellers)

THP: Thrust horse power

P_T = Thrust x speed of advance = $T \times V_A$

$\eta_{H:}$ Hull efficiency = $P_E / P_T = (R_T \times V) / (T \times V_A)$

Q_D: Torque required by the propeller to deliver T at V_A behind the ship

P_D: Power delivered to the propeller by the prime mover = $2 \times \pi \times n \times Q_D$

η_B: Propeller efficiency behind the ship = $P_T / P_D = (T \times V_A) / (2 \times \pi \times n \times Q_D)$

Q_0: Torque required by the propeller to deliver T at V_A in open water

η_0: Propeller efficiency in open water = $(T \times V_A) / (2 \times \pi \times n \times Q_0)$

η_R: Relative rotative efficiency = η_B / η_0

P_S: Shaft power (power before the stern tube bearing)

SHP: Shaft horse power

P_B: Brake power (power of the prime mover --diesel engines, gas turbines etc.--)

BHP: Brake horse power

η_S: Shaft transmission efficiency = P_D / P_S

η_P: Overall propulsive efficiency (also known as Propulsive Coefficient (PC))

η_P $= P_E / P_S = (P_E / P_T) \times (P_T / P_D) \times (P_D / P_S) = \eta_H \times \eta_B \times \eta_S = \eta_H \times \eta_0 \times \eta_R \times \eta_S$

D: Propeller diameter

d: Propeller hub diameter

t_o : Thickness of blade at hub

t_o / D: Blade thickness fraction (ratio)

c: Chord

J: Advance ratio = $V_A / (n \times D)$

ρ: Mass density of water

K_T: Thrust coefficient = $T / (\rho \times n^2 \times D^4)$

K_Q: Torque coefficient = $Q / (\rho \times n^2 \times D^5)$

η_0 = $(J / 2\pi) \times (K_T / K_Q)$

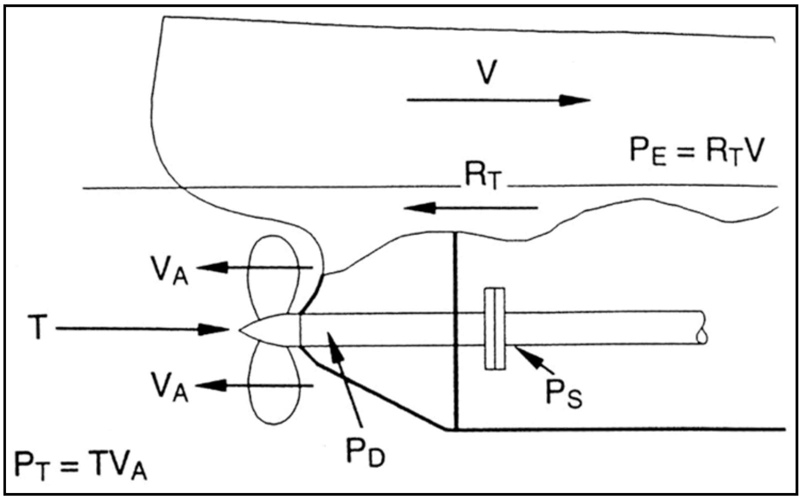

Figure 38. Sketch of Resistance and Propulsion (From [91])

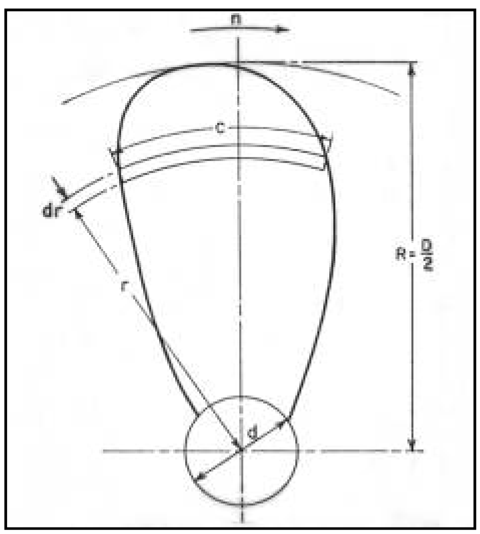

Figure 39. Sketch of a Typical Propeller Blade (From [92])

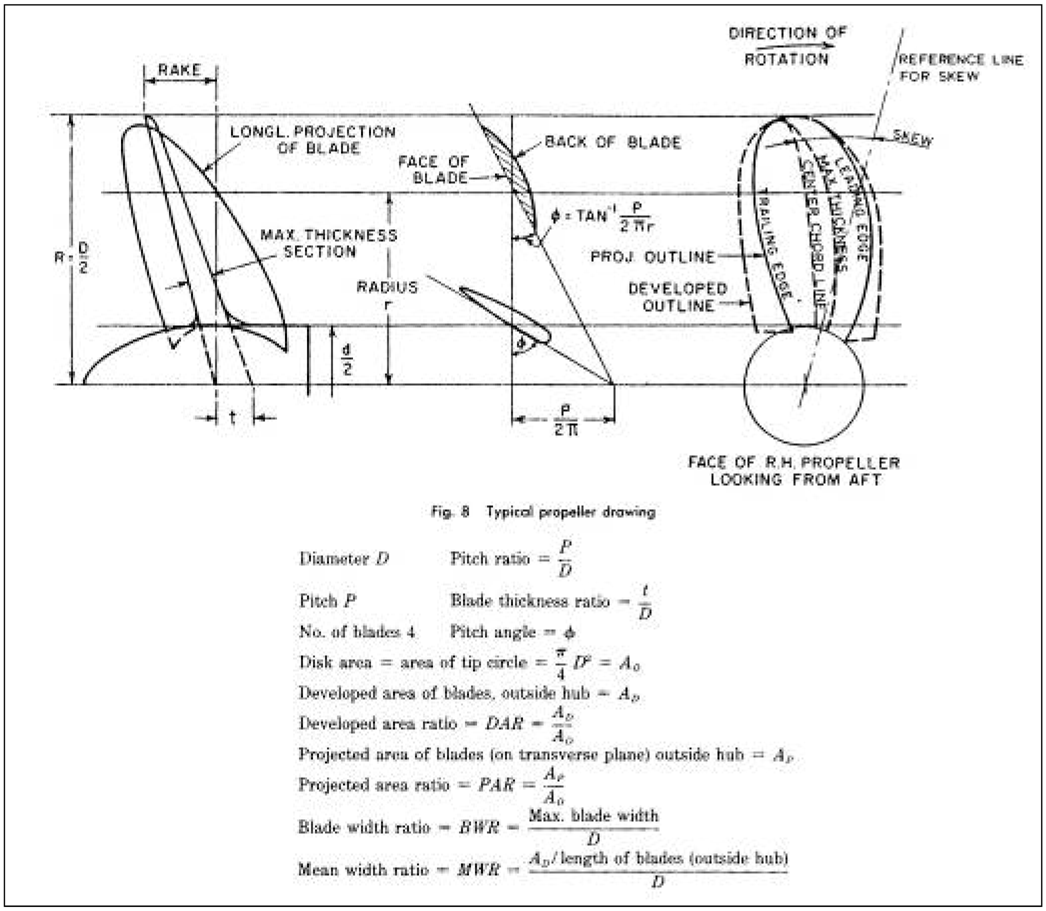

Figure 40. Typical Propeller Blade Drawings and Definitions (From [92])

3. Calculating the Efficiency Loss after Wrapping

These are the factors that cause the efficiency loss and increase in resistance after wrapping:

- Increasing the hub diameter
- Increasing the thickness of the blades (blade thickness fraction (ratio) = *t/D*)
- Increasing the blade area
- Increasing the roughness (surface friction of the blades)
- Other effects (increasing the appendage resistance, friction on shaft and changing the flow characteristics).

a. Increasing the Hub Diameter

Both experimental and computational methods are considered to demonstrate the loss of propeller efficiency caused by increasing the hub diameter. Figure 41 shows the experimental results by D.W. Taylor [93]. Simply, increasing the hub diameter causes a loss in propeller efficiency, torque and thrust coefficients.

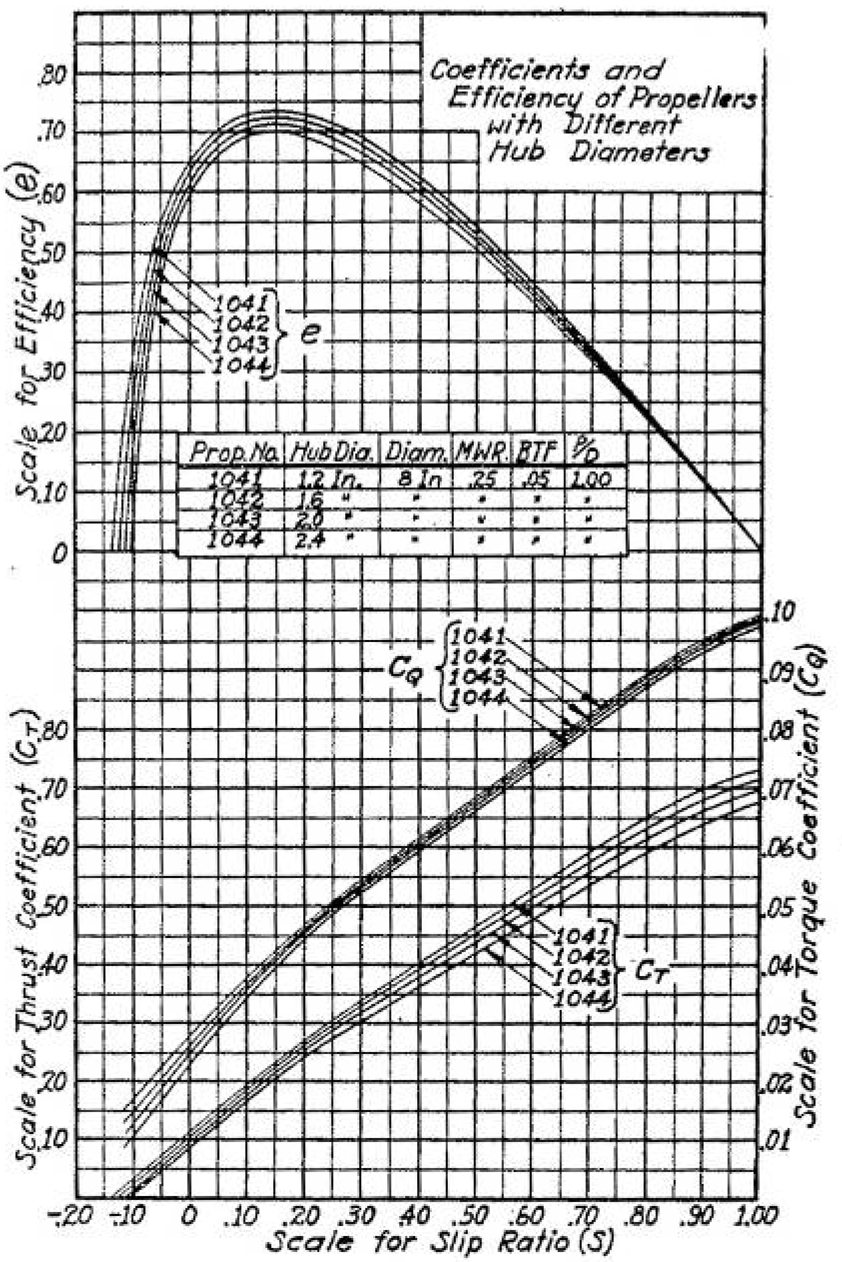

Figure 41. Experimental Results of Increasing Hub Diameter (From [93])

A MATLAB code named OpenProp v2.4.6 is used to show the computational results [94]. OpenProp is an open-source code suite created by a team of researchers at Massachusetts Institute of Technology (MIT) and the Maine Maritime Academy for designing optimized marine propellers or axial-flow turbines.

First, the propeller diameter and the propeller speed values are found by using the “parametric study” option of the OpenProp v2.4.6. For parametric study, the hub diameter is assumed to be 0.4 meters (default value). In general, the hub diameter of ships varies from 0.15*D* to 0.25*D* [92]. Therefore, the default value of 0.4 meters is proper. This is important because the program designs the propeller based on this hub diameter, and the same propeller will be used for the analysis.

For the parametric study, the number of blades, propeller speed (RPM) and propeller diameter all has variable values. Other terms like *required thrust*, *ship velocity*, *hub diameter*, and *water density* have constant values. The thickness type NACA 65A010 and the mean-line type NACA a=0.8 are used for all calculations.

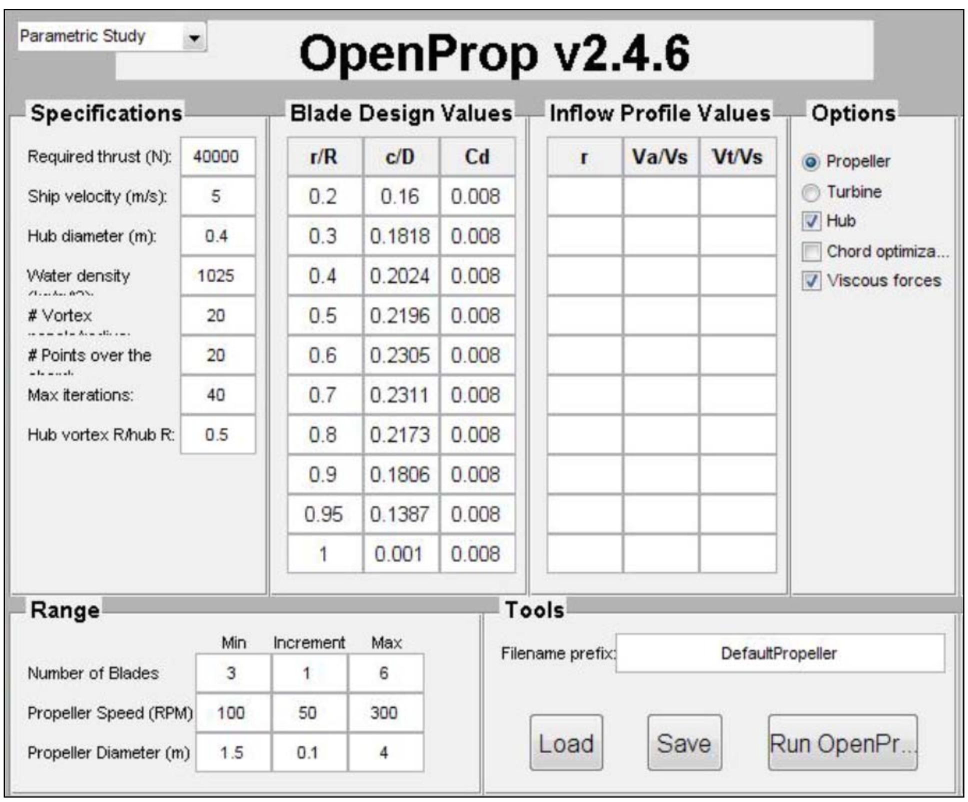

Figure 42. Input Values for the Parametric Study

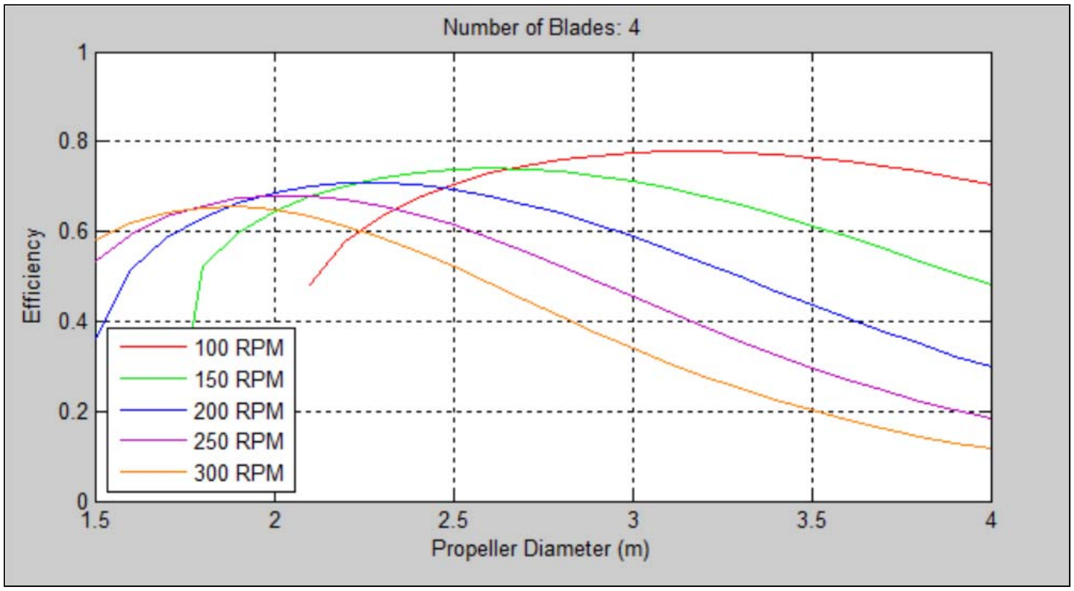

Figure 43. Results of the Parametric Study

Based on the results (4-blade propeller - sample ship), three different cases of propeller diameter and speed values were selected (for the highest efficiency).

- Case 1:Propeller diameter = 2.3 m. Propeller speed = 200 RPM
- Case 2:Propeller diameter = 2.5 m. Propeller speed = 150 RPM
- Case 3:Propeller diameter = 3 m. Propeller speed = 100 RPM

In all cases, the ship's speed is assumed to be 5 m/s (9.71 knots). There are two reasons for this decision. First, the sample ship has an average speed of 9.1 knots and a maximum speed of 10.5 knots, based on the information by AIS [81]. Second, there is a speed limit in the Turkish Straits. Maritime Traffic Regulations for the Turkish Straits (Article 13) restrict vessels within the straits to cruising at a speed not more than 10 knots over the ground [73].

Then the "single design" option of the OpenProp v2.4.6 is used to calculate the change in propeller efficiency with respect to the increasing hub diameter. In all cases, I used the initial value of 0.4 m. for the hub diameter for the first calculation. Then I increased the hub diameter and recalculated the efficiency. The increase in the hub diameter is assumed to be the wrapped thickness of the ropes or nets around the propeller.

Based on the results of OpenProp v2.4.6 the propeller efficiency vs. wrapped diameter values are plotted for each case.

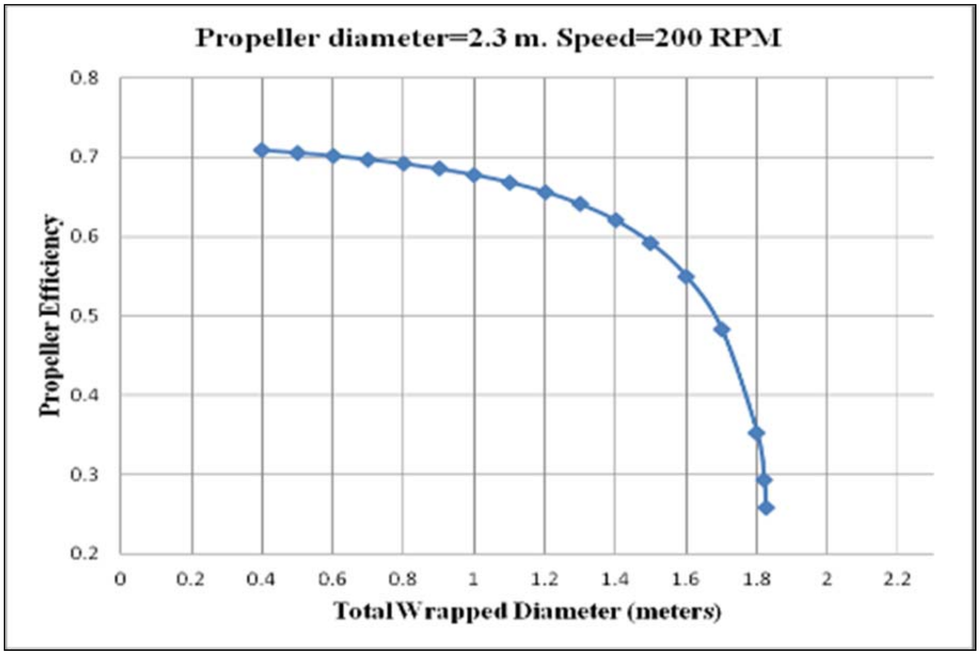

Figure 44. Case 1: Loss of Efficiency by Wrapping

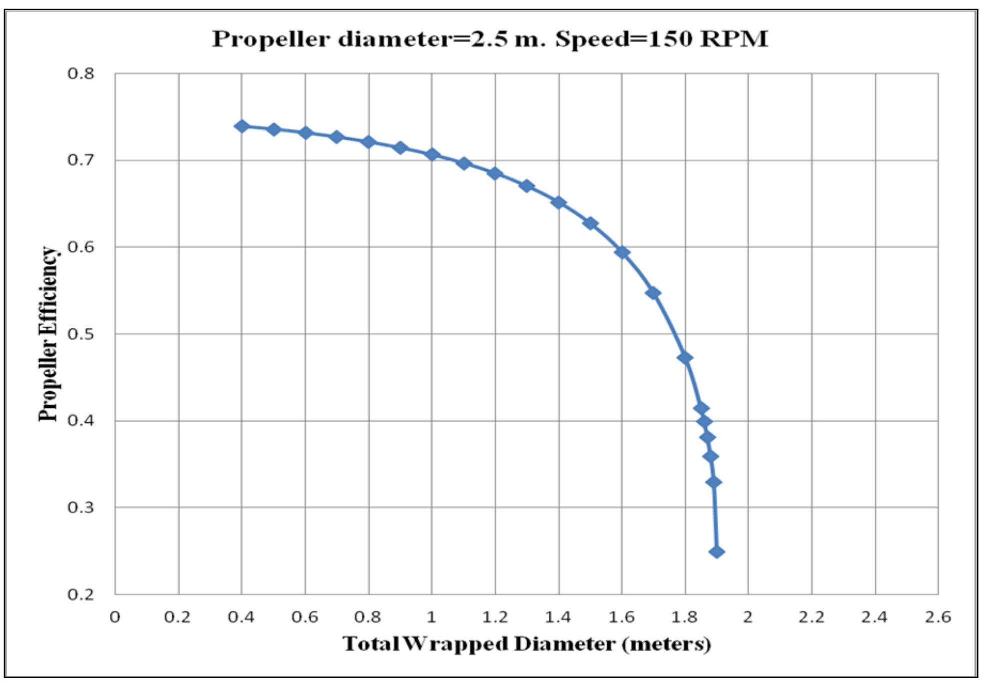

Figure 45. Case 2: Loss of Efficiency by Wrapping

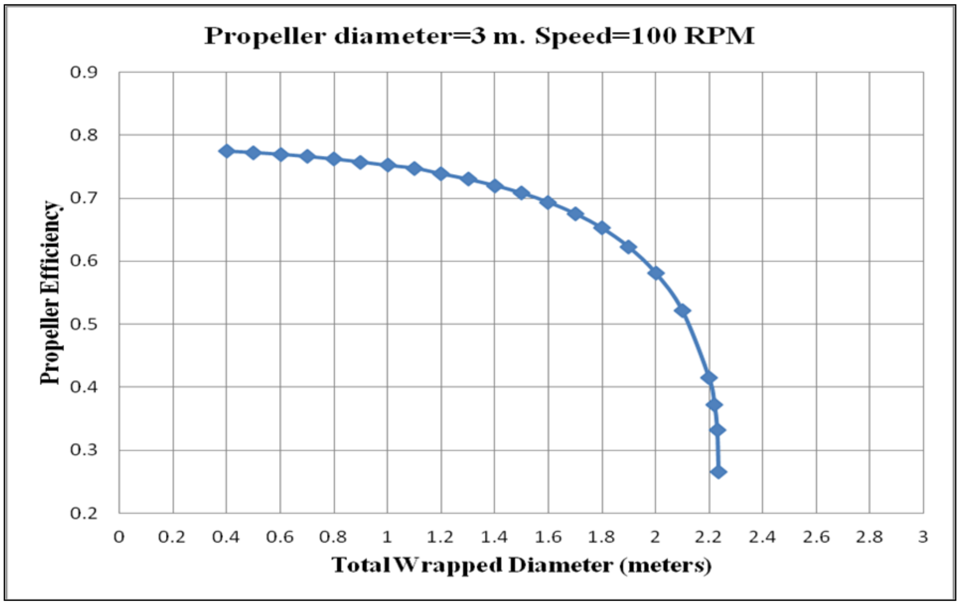

Figure 46. Case 3: Loss of Efficiency by Wrapping

Based on these graphs, it is obvious that decreasing propeller efficiency by wrapping ropes or nets around the propeller hub is possible. In all cases, there is a sudden decrease in efficiency after a specific increase in wrapped hub diameter.

Case	Propeller Diameter	Initial Hub Diameter	Diameter for ~ 50% Loss in Efficiency	Diameter Ratio for 50% Loss	Diameter for ~ 65% Loss in Efficiency	Diameter Ratio for 65% Loss
1	2.3 m.	0.4 m.	1.8 m.	78.26%	1.825 m.	79.35%
2	2.5 m.	0.4 m.	1.88 m.	75.20%	1.9 m.	76.00%
3	3 m.	0.4 m.	2.22 m.	74.00%	2.235 m.	74.50%

Table 15. Summary of the Results for Case 1,2 and 3

Based on the results of OpenProp v2.4.6, when the wrapped diameter of the hub reaches three-fourths of the propeller diameter, there is an approximately 50% decrease in efficiency. After this critical diameter, an additional roughly 1% increase in wrapped diameter will cause an approximate 15% loss in efficiency. Therefore, the ropes or nets must be wrapped around the hub to more than three-fourths of the propeller diameter.

The Case 2 is selected to demonstrate loss of efficiency and loss of speed.

Total Diameter (meters)	Propeller Efficiency	Speed (m/s)	Speed (knots)
0.4	0.73905	5.00	9.71
0.5	0.73577	4.98	9.67
0.6	0.73170	4.95	9.62
0.7	0.72685	4.92	9.55
0.8	0.72113	4.88	9.48
0.9	0.71438	4.83	9.39
1.0	0.70637	4.78	9.28
1.1	0.69674	4.71	9.16
1.2	0.68498	4.63	9.00
1.3	0.67034	4.54	8.81
1.4	0.65172	4.41	8.57
1.5	0.62735	4.24	8.25
1.6	0.59429	4.02	7.81
1.7	0.54707	3.70	7.19
1.8	0.47311	3.20	6.22
1.85	0.41425	2.80	5.44
1.86	0.39867	2.70	5.24
1.87	0.38074	2.58	5.00
1.88	0.35912	2.43	4.72
1.89	0.32914	2.23	4.33
1.9	0.24961	1.69	3.28

Table 16. Results for the Case 2

Then the “3-D Geometry Results” of the OpenProp v2.4.6 is used to visualize the wrapping of Case 2. The dark gray parts of the drawings represent the ropes or nets wrapped around the light gray-colored propeller’s hub.

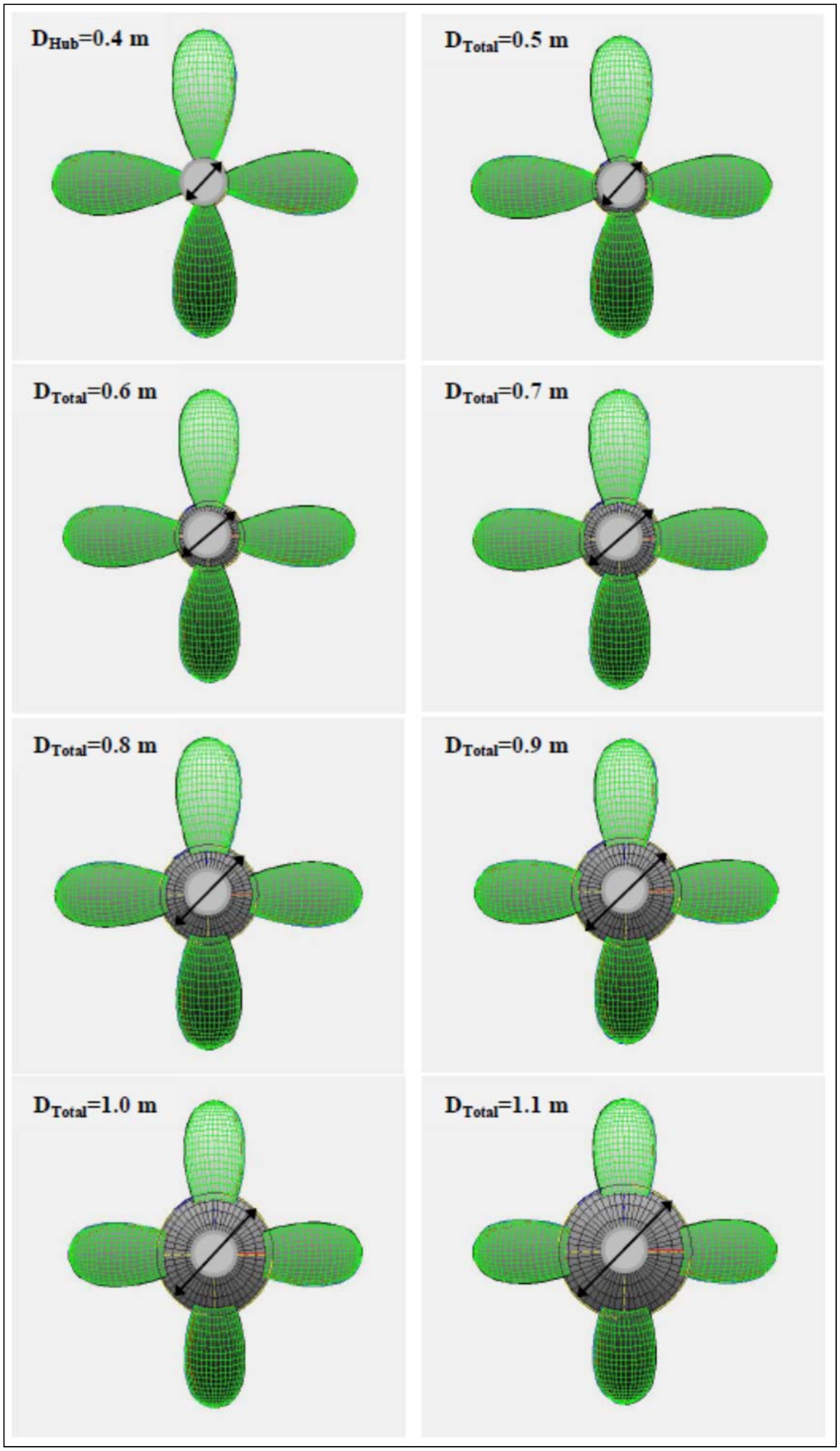

Figure 47. Case 2: Wrapped Diameter from 0.4 to 1.1 m.

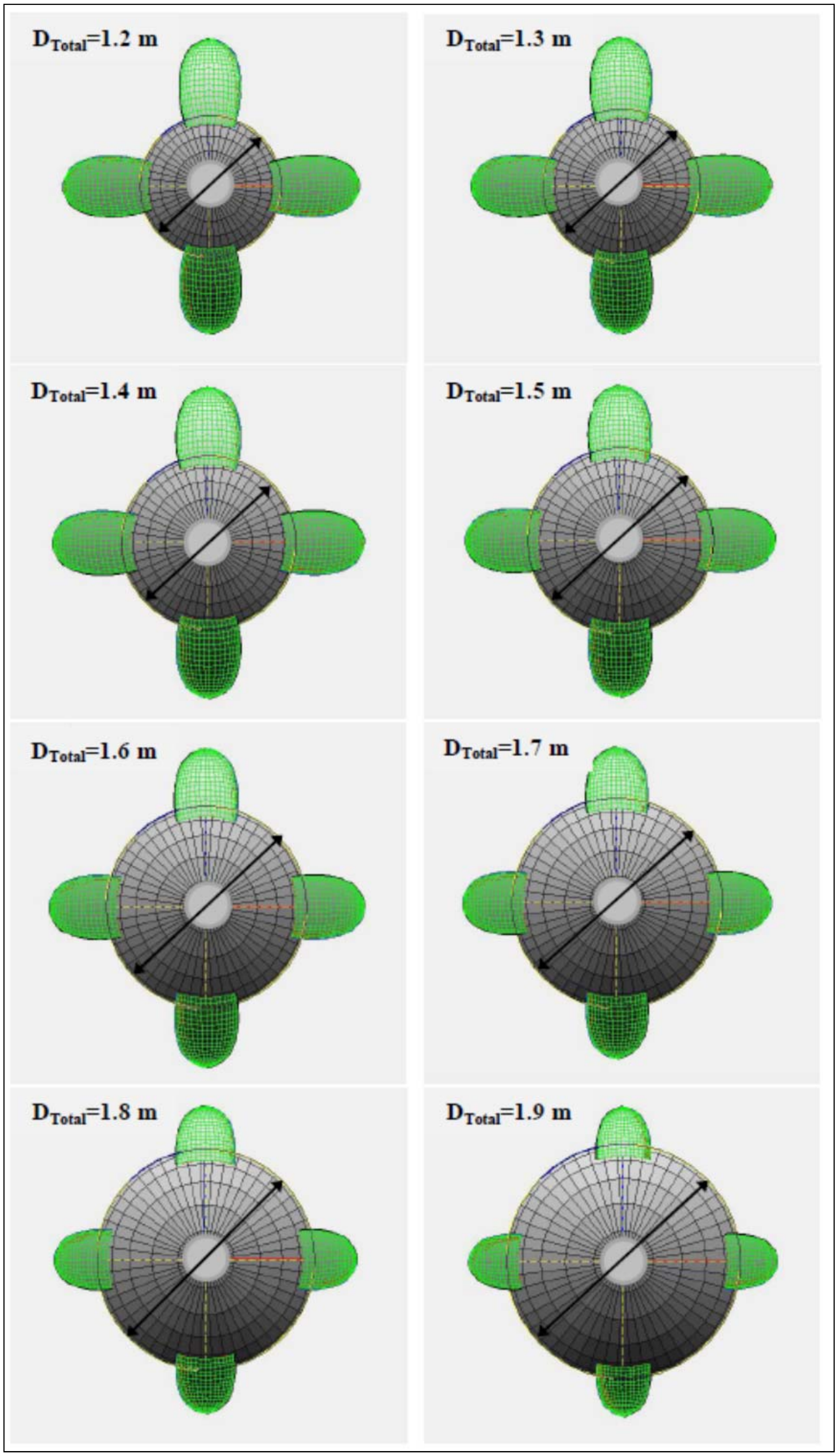

Figure 48. Case 2: Wrapped Diameter from 1.1 to 1.9 m.

b. Increasing the Thickness of the Blades

Experimental results are considered to demonstrate the loss of propeller efficiency caused by increasing the thickness of the blades after wrapping. In one of his experiments, D.W. Taylor used 12 blades to analyze efficiency due to blade thickness. Six of the blades had a pitch ratio of 0.6, and the other 6 blades had a pitch ratio of 1.2. For each different pitch ratio, two different blade widths were chosen, and for each of these different widths, three different blade thicknesses were used. Figure 49 summarizes the different blades which were used for the experiments of D.W. Taylor [95].

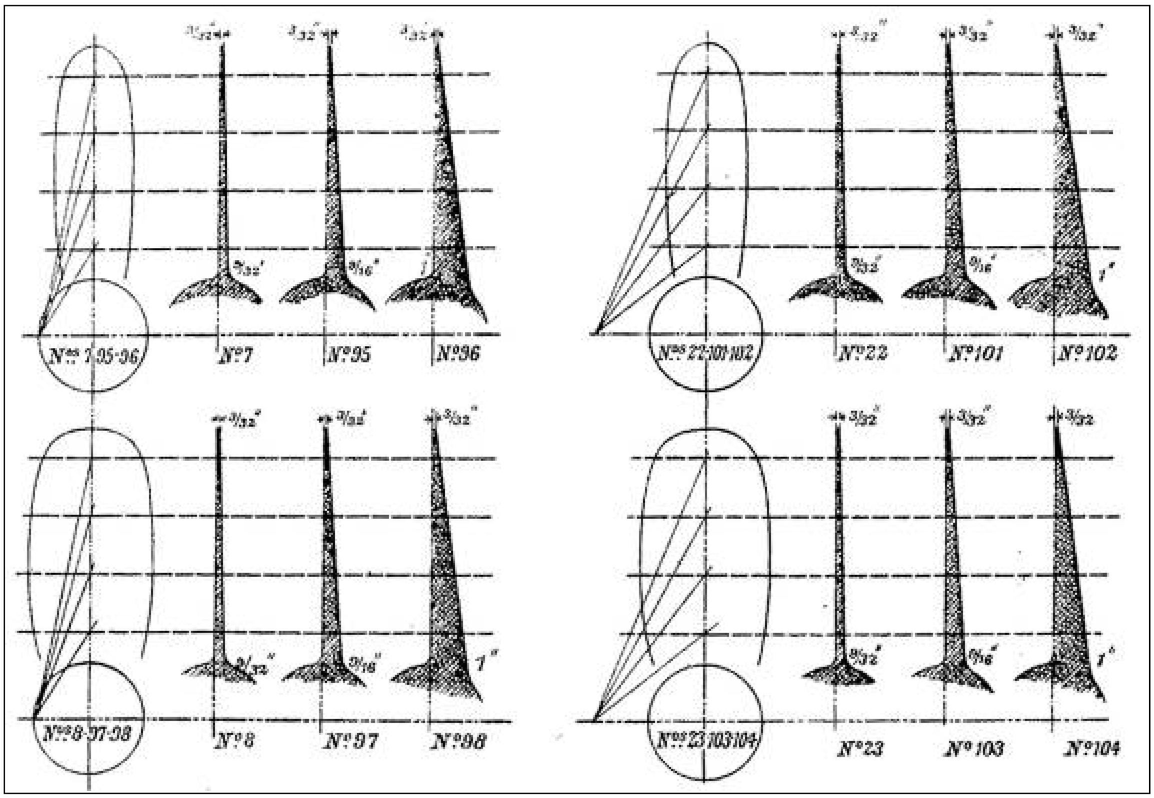

Figure 49. Sets of Blades Used by D.W. Taylor for the Experiments (From [95])

Based on D.W. Taylor's experimental results, J.H. Biles [95] notes that,

> The results obtained show clearly that there is a falling off in efficiency with an increase of blade thickness, and that such increase causes a marked increment in the power absorbed and thrust delivered. It seems to be a fair conclusion that, if the type of blade section remains constant, any increase of blade thickness will cause a loss of efficiency....

Simply, increasing the blade thickness causes a loss in propeller efficiency. Figure 50 shows the loss of efficiency due to the increase of blade thickness fraction (ratio) [95].

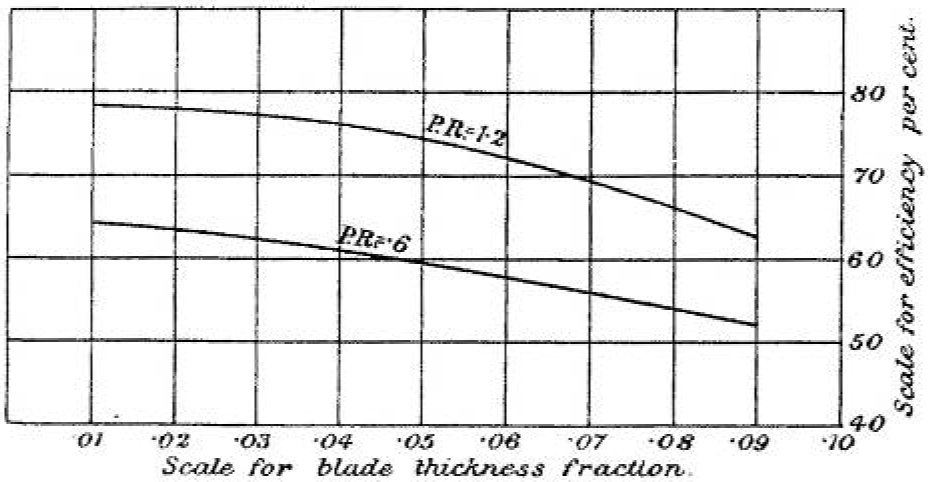

Figure 50. Efficiency vs. Blade Thickness Fraction (From [95])

Case 2 (propeller diameter=2.5 m and propeller speed=150 RPM) is used to find the estimated loss of efficiency for the sample ship's propeller. The blade thickness fraction is 0.032896 for the initial calculations of efficiency by OpenProp v2.4.6. Figure 52 shows the blade thickness of this initial blade thickness fraction (ratio).

- D = 2.5 m.
- t_o / D = 0.032896
- t_o = 0.08224 m.

It is assumed (1) the ropes or nets are wrapped around the propeller blades uniformly, and (2) there are 5 cm. thick ropes or nets on each side of the blade after wrapping. Therefore, the total thickness of the wrapped ropes or nets is 10 cm. As a result, the blade thickness fraction becomes 0.072896. Table 17 shows the calculation of the blade thickness ratio after wrapping.

Because the OpenProp v2.4.6 does not include blade thickness in performance calculations (efficiency stays the same after a change of thickness) [96], the software is only used to demonstrate the blade thickness profiles before and after wrapping.

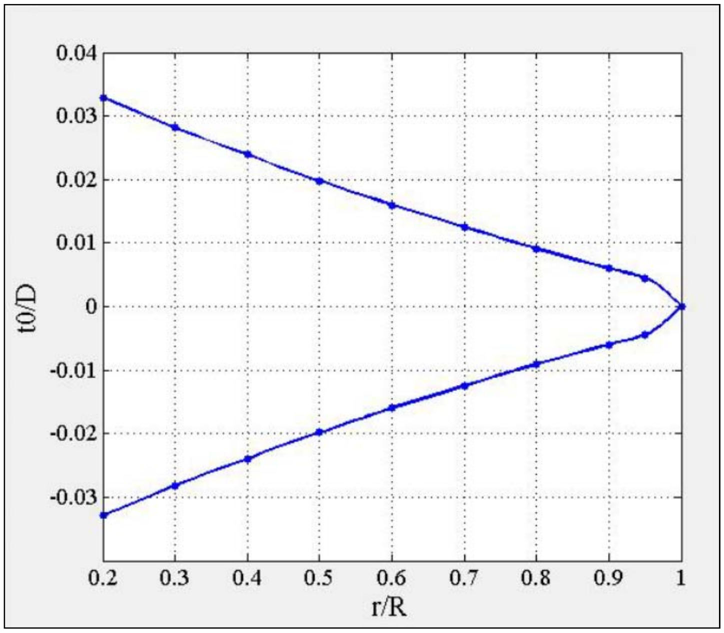

Figure 51. Blade Thickness of Case 2 before Wrapping

r/R	***t_o/D***	***D (meter)***	***t_o (meter)***	***Wrapped Ropes/Nets (meter)***	***Total Thickness After Wrapping***	***t_o/D After Wrapping***
0.2	0.032896	2.5	0.08224	0.1	0.18224	0.072896
0.3	0.028197	2.5	0.07049	0.1	0.17049	0.068197
0.4	0.023903	2.5	0.05976	0.1	0.15976	0.063903
0.5	0.019808	2.5	0.04952	0.1	0.14952	0.059808
0.6	0.015997	2.5	0.03999	0.1	0.13999	0.055997
0.7	0.012503	2.5	0.03126	0.1	0.13126	0.052503
0.8	0.009105	2.5	0.02276	0.1	0.12276	0.049105
0.9	0.005996	2.5	0.01499	0.1	0.11499	0.045996
0.95	0.004494	2.5	0.01123	0.1	0.11123	0.044494
1.0	0.000010	2.5	0.00003	0.1	0.10003	0.040010

Table 17. Calculation of Blade Thickness Fraction after Wrapping

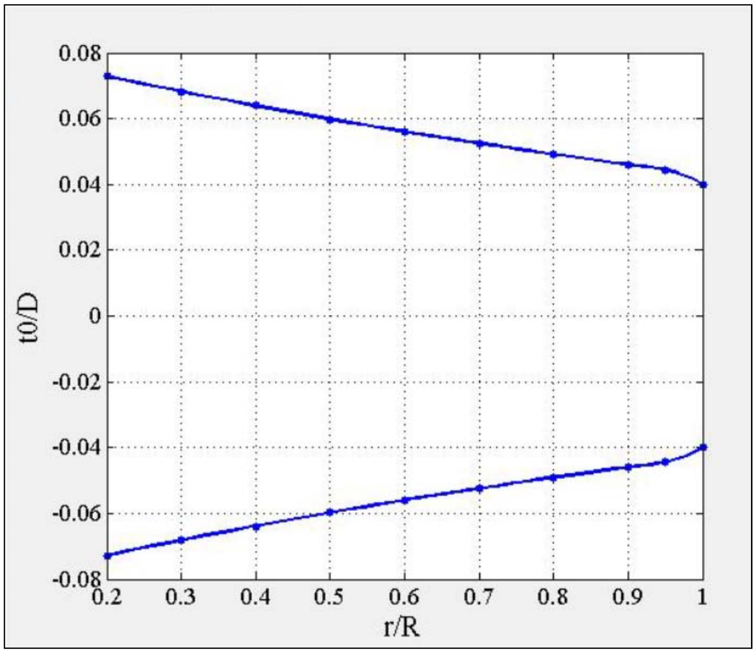

Figure 52. Blade Thickness of Case 2 after Wrapping

The hub diameter is assumed constant during the wrapping. Therefore, the experimental results of D.W. Taylor can be used to calculate the loss of efficiency after wrapping. The blade thickness fraction ratio is:

- t_o / D = 0.072896 (after wrapping)
- t_o / D = 0.032896 (before wrapping)
- *Ratio* = 2.216

Based on the difference of the blade thickness fraction after wrapping, using Figure 50 yields these results:

- For pitch ratio=1.2, efficiency decreases from approximately 77% to 68%
- For pitch ratio=0.6, efficiency decreases from approximately 62% to 55%

Finally, there is an average of 8% loss of efficiency because of the 10 cm. increase in the design blade thickness after wrapping.

c. Increasing the Blade Area

Experimental results are considered to demonstrate the loss of propeller efficiency caused by increasing the blade area after wrapping. D.W. Taylor used 120 blades to analyze the effects of blade area, thickness and pitch ratio on efficiency. In the experiments, three-bladed propellers with 0.4 m (16 inches) diameter were used. There were six pitch ratios (0.6, 0.8, 1.0, 1.2, 1.5, 2.0) with five different blade areas for each pitch ratio. The mean width ratios of the blades were 0.15, 0.20, 0.25, 0.30 and 0.35. The thicknesses of the blades were reduced (from original cut to A-, B- and C-cut) after each experiment. Four different thicknesses were used for each propeller, and 120 different propellers were analyzed totally. [97], [98]

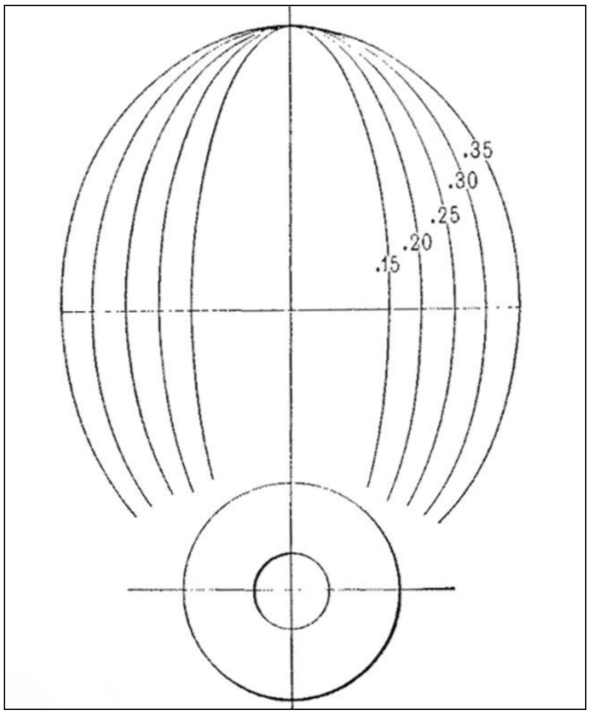

Figure 53. Blade Mean Width Ratios (From [98])

Similar to the effects of increasing blade thickness, an increase of the blade area causes the loss of efficiency. In conclusion, there is 5% to 10% decrease of efficiency based on the increase of design blade area. [97], [98]

PROPELLER NO.	PITCH IN INCHES	PITCH RATIO	MEAN WIDTH RATIO	PROJECTED AREA ÷ DISC AREA	BLADE THICKNESS FRACTION			
					ORIGINAL THICKNESS	A-CUT	B-CUT	C-CUT
1	9·6	.6	·15	·2129	·1033	·0774	·0516	·0258
2	,,	,,	.20	·2838	·0894	·0672	·0448	·0224
3	,,	,,	·25	·3548	·0800	·0600	·0400	·0200
4	,,	,,	·30	·4257	·0730	·0544	·0363	·0181
5	,,	,,	·35	·4966	·0676	·0507	·0338	·0169
6	12·8	.8	·15	·2023	·1033	·0774	·0516	·0258
7	,,	,,	·20	·2698	·0894	·0672	·0448	·0224
8	,,	,,	·25	·3373	·0800	·0600	·0400	·0200
9	,,	,,	·30	·4047	·0730	·0544	·0363	·0181
10	,,	,,	·35	·4721	·0676	·0507	·0338	·0169
11	16.	1.0	·15	·1919	·1033	·0774	·0516	·0258
12	,,	,,	·20	·2557	·0894	·0672	·0448	·0224
13	,,	,,	·25	·3198	·0800	·0600	·0400	·0200
14	,,	,,	·30	·3837	·0730	·0544	·0363	·0181
15	,,	,,	·35	·4476	·0676	·0507	·0338	·0169
16	19·2	1·2	·15	·1814	·1033	·0774	·0516	·0258
17	,,	,,	·20	·2418	·0894	·0672	·0448	·0224
18	,,	,,	·25	·3023	·0800	·0600	·0400	·0200
19	,,	,,	·30	·3627	·0730	·0544	·0363	·0181
20	,,	,,	·35	·4231	·0676	·0507	·0338	·0169
21	24.	1.5	·15	·1656	·1033	·0774	·0516	·0258
22	,,	,,	·20	·2209	·0894	·0672	·0448	·0224
23	,,	,,	·25	·2761	·0800	·0600	·0400	·0200
24	,,	,,	·30	·3313	·0730	·0544	·0363	·0181
25	,,	,,	·35	·3865	·0676	·0507	·0338	·0169
26	32.	2.0	·15	·1394	·1033	·0774	·0516	·0258
27	,,	,,	·20	·1887	·0894	·0672	·0448	·0224
28	,,	,,	·25	·2323	·0800	·0600	·0400	·0200
29	,,	,,	·30	·2788	·0730	·0544	·0363	·0181
30	,,	,,	·35	·3253	·0676	·0507	·0338	·0169

Table 18. Propellers Used in Taylor's Experiments (From [98])

Table 18 shows the properties of the 120 propellers used by Taylor, and Figure 54 is used as an example to demonstrate the effects of blade area and thickness on efficiency.

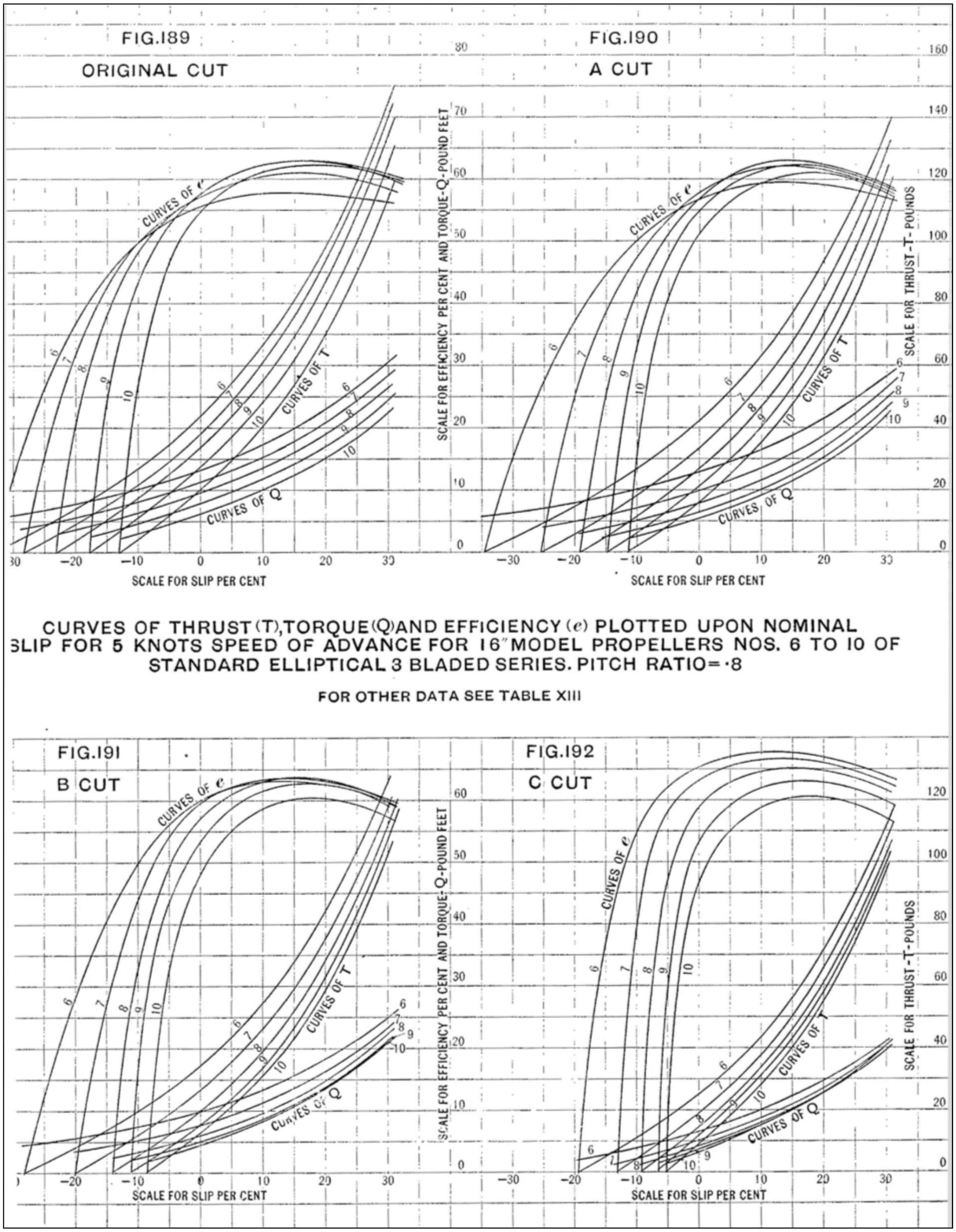

Figure 54. Effects of Blade Area and Thickness on Efficiency (From [98])

d. Increasing the Roughness (Blade Surface Friction)

As mentioned before, it is assumed that the ropes or nets become part of the blades after wrapping. Because of the difference in material properties, the roughness of the blades will be increased after wrapping. Experimental results are considered to demonstrate the loss of propeller efficiency caused by increase in blade roughness.

Based on the works of W. McEntee [99], D.W. Taylor mentions,

> Probably no controllable feature of a propeller designed to meet given conditions has as much influence upon efficiency as the nature and condition of its surface…. There seems good reason to believe that the efficiency of new cast iron or steel propellers, or bronze propellers in moderately good (not bad) condition, is generally some 10 percent below that of new accurately finished bronze propellers made as smooth as possible. In other words, the vast majority of existing ships are probably operating with an avoidable waste of power of the order of 10 percent [93].

Figures 55 and Figure 56 show the negative effect of roughness on propeller efficiency.

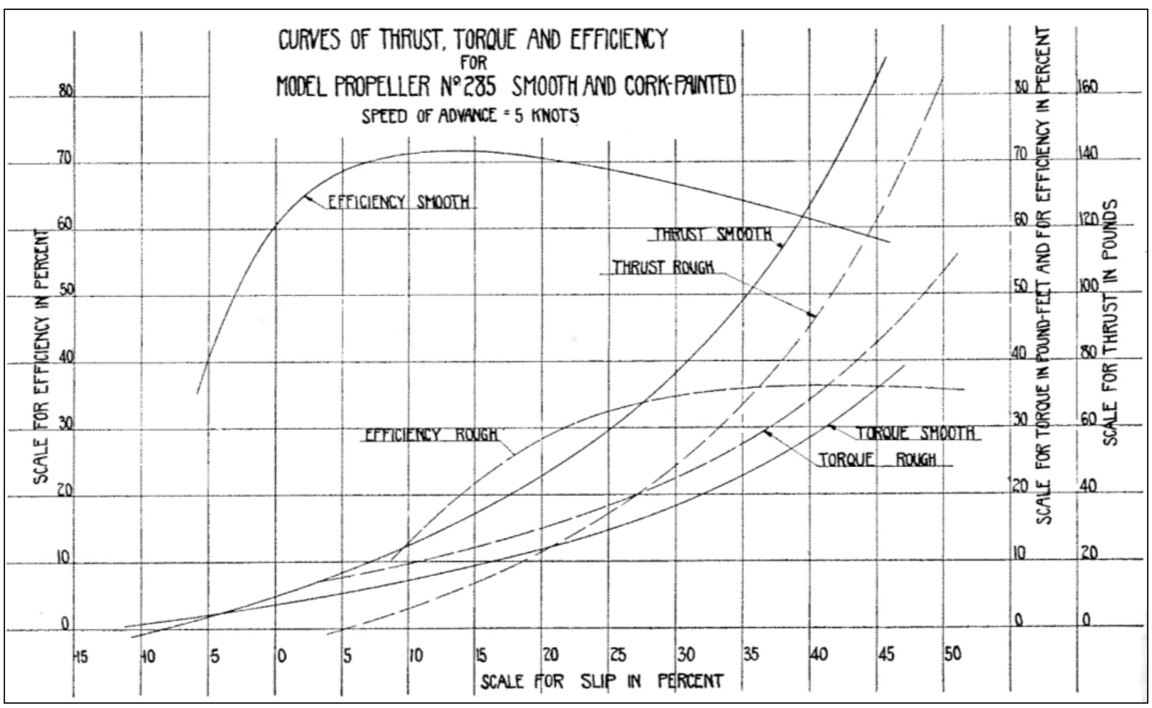

Figure 55. Effects of Roughness on Efficiency (From [93])

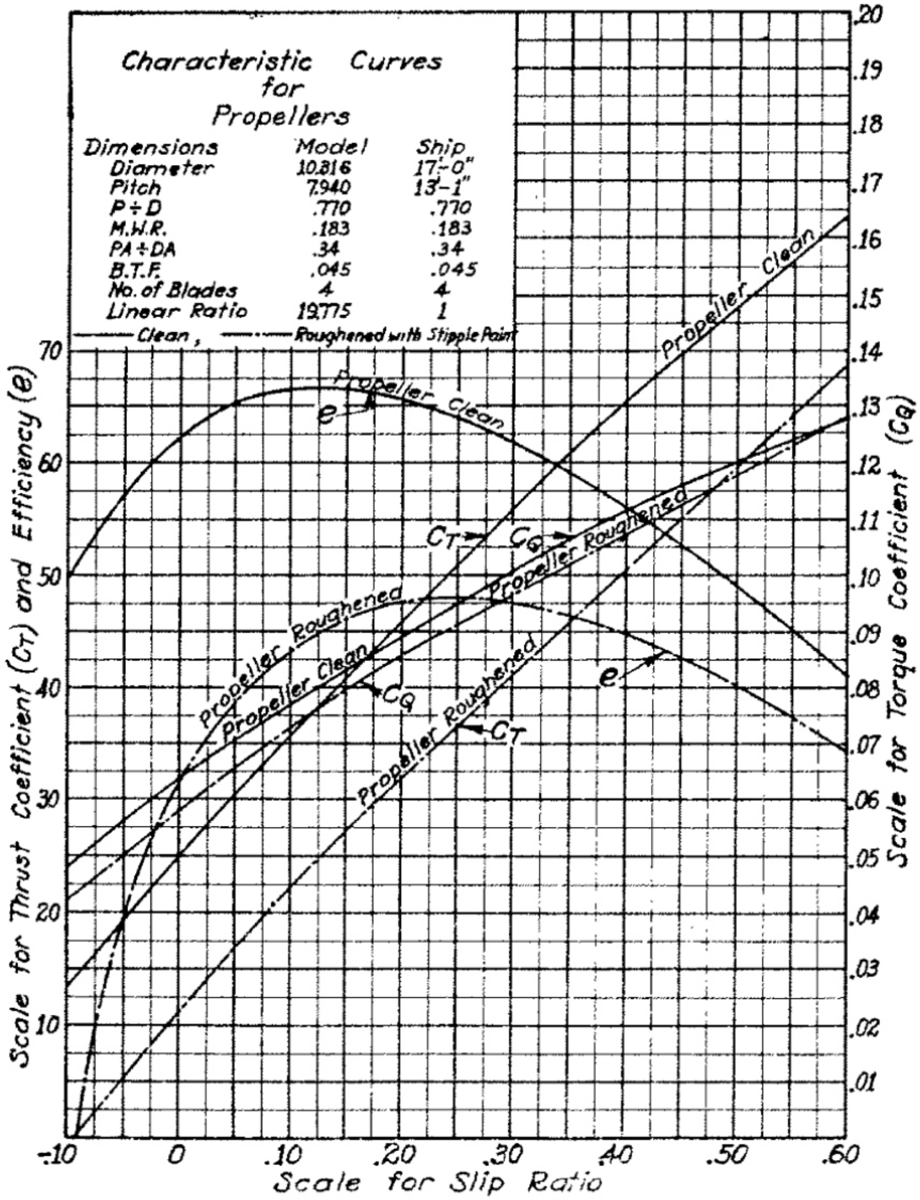

Figure 56. Efficiency Loss due to Roughness (From [93])

It is obvious that the negative effect of wrapped ropes and nets on propeller efficiency is greater than the effect of natural roughness. Based on the Figures 55 and Figure 56, it is assumed that there will be a minimum 30% loss of efficiency due to the increased roughness (blade surface friction) after wrapping.

e. Other Factors

There are other factors that cause the loss of efficiency and/or increase of resistance. Simply, the wrapped ropes or nets will cause:

- Increase of the appendage resistance,
- Increase of the total weight of the ship (so required thrust increases),
- A decrease in the quality of the flow around the propeller,
- Friction on shaft (loss in shaft efficiency).

f. Using Computational Fluid Dynamics (CFD) for Calculating the Loss of Efficiency after Wrapping

The OpenProp v2.4.6 creates an output file which has all the geometrical information of the designed propeller blade. Using this file, it is easy to create a solid blade in SolidWorks software. Figure 57 shows the curves of the blade for Case-2 which are created in SolidWorks by using coordinates provided by OpenProp v2.4.6.

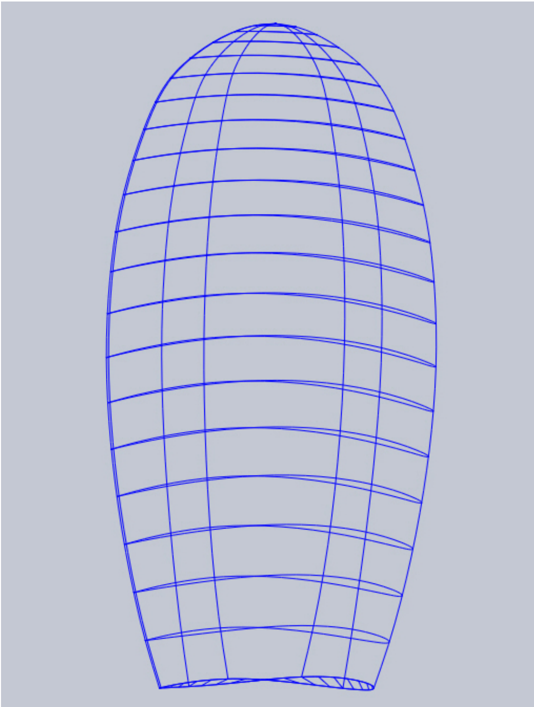

Figure 57. Geometry of the Propeller Blade for Case 2

Figure 58 shows the solid blade created in SolidWorks after selection of the blade's material.

Figure 58. Solid Blade after Material Selection for Case 2

After creating the solid blade in SolidWorks, the blade can be opened with the ANSYS software. Figure 59 shows the solid blade opened in ANSYS. Both in SolidWorks and in ANSYS, the whole propeller and the ropes or nets wrapped around the propeller can be drawn. After that, the flow around the propeller and wrapped ropes or nets can be defined in ANSYS. In this way, the wrapping can be simulated, and the propeller efficiency after wrapping can be calculated using the CFD codes of ANSYS.

In conclusion, there are computational methods for calculating the loss of propeller efficiency after wrapping. However, because of the random nature of the wrapping, different wrapping patterns must be created to compare the results. In this research, the CFD method is not used because of time limitations.

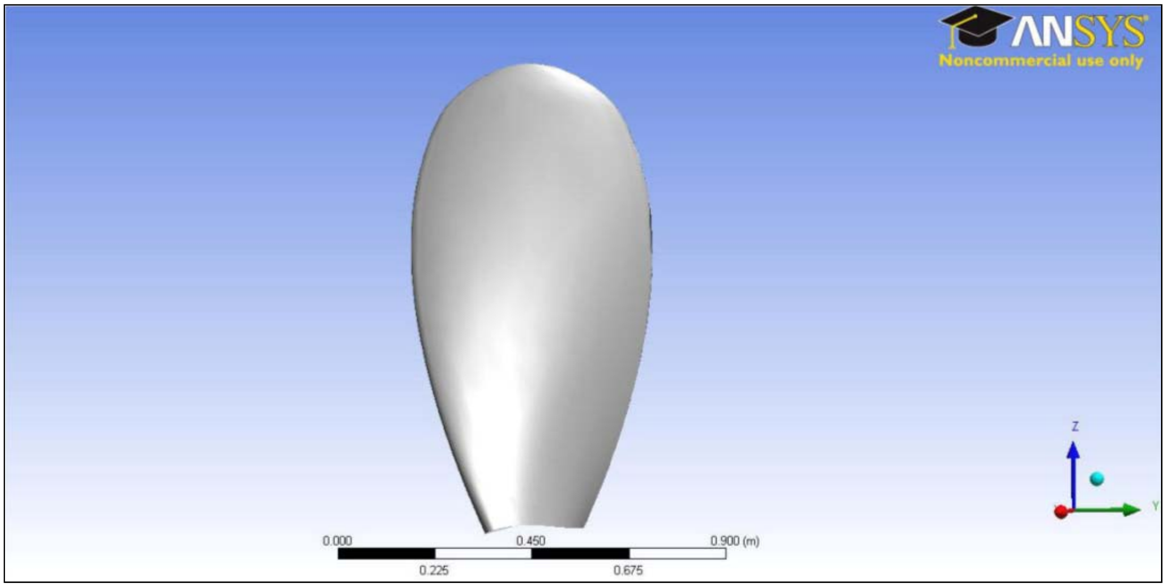

Figure 59. Solid Blade in ANSYS for Case 2

g. Summary of the Efficiency Analysis after Wrapping

The effects of wrapping ropes or nets around the propeller and its hub were analyzed. These are the main results of the efficiency analysis after wrapping:

- If the wrapped diameter of the hub reaches three-fourths of the diameter of the propeller, the loss of efficiency will be greater than approximately 50%.
- There is an average of 8% loss of efficiency because of the 10 cm. increase of the design blade thickness after wrapping.
- There will be a minimum 30% loss of efficiency due to the increased roughness (blade surface friction) after wrapping.
- There will be 5% to 10% decrease of efficiency based on the increase of design blade area.
- There are other factors, such as increase of appendage resistance and friction on the shaft, that reduce efficiency.

Based on these results, it is possible to stop a ship by successfully wrapping ropes or nets around the propeller and its hub. Even if the propeller of the ship continues to turn after wrapping, the loss of efficiency will exceed 90%. For the most probable scenario, the efficiency of the sample ship's designed propeller will be impeded after the successful wrapping.

The sample ship has an average speed of 9.1 knots and a maximum speed of 10.5 knots based on information from AIS [81]. The sample ship voyages from north to south, and the average current in the northern entrance of the Istanbul Strait is 1 knot [15]. As mentioned before, there is a speed limit regulation in the Turkish Straits. Based on Maritime Traffic Regulations for the Turkish Straits (Article 13), the vessels within the straits may not cruise at a speed more than 10 knots over the ground [73].

As mentioned before, the propeller efficiency is one of the factors of the overall propulsive efficiency [91, 92].

η_H: Hull efficiency

η_B: Propeller efficiency behind the ship

η_S: Shaft transmission efficiency

η_P: Overall propulsive efficiency

$$\eta_P = \eta_H \times \eta_B \times \eta_S$$

Therefore, the speed of the sample ship will be approximately 1 knot after the successful wrapping. Together with the average current, the maximum speed of the sample ship will be approximately 2 knots. The underwater system must be designed based on this criterion.

VII. DESIGN OF THE UNDERWATER SYSTEM

Computational and experimental results demonstrate that the loss of efficiency will be greater than 90% after successful wrapping. With the average current at the northern entrance of the Istanbul Strait, the speed of the sample ship will be approximately 2 knots. Based on this information, the design criteria are:

- The underwater system must be designed to wrap the ropes or nets around terrorist ship’s propeller and its hub successfully, and…
- The underwater system must hold the ship like an anchor after wrapping.

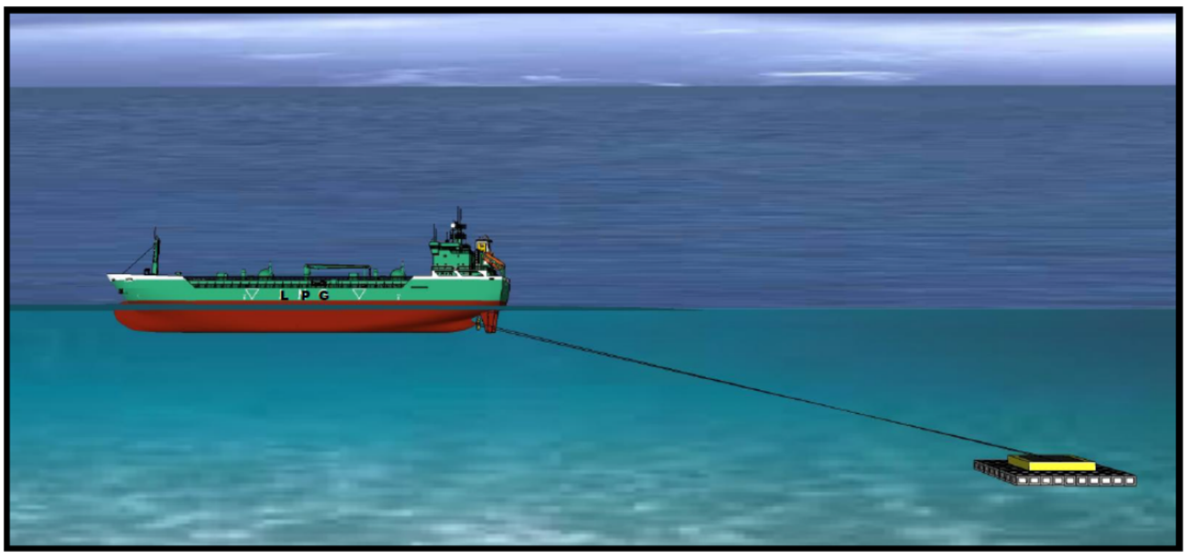

Figure 60. Sketch of the Underwater System and the Stopped Ship

The Google SketchUp 8 software is used to draw the underwater system [100]. The software has an internet based model bank named “Google 3D Warehouse.” The ship model in the drawings is selected from this warehouse [89].

The working principle of the underwater system is based on the acoustic radiation of the propeller. Sensors detect the source of noise (the propeller of the ship), and UUVs will carry and throw ropes and nets to the source. The underwater system is designed to stop the sample ship, which has one propeller.

To meet design criteria, the underwater system must consist of components such as the UUVs, a command and control station, acoustic sensors, an artificial reef, waterproof tank(s), and ropes and nets to wrap around the propeller. The functions of these elements are described in this chapter. Power requirements, weight and strength calculations, acoustics, underwater positioning methods, the wrapping mechanism and the material selection of the underwater system are outside the scope of this research.

A. COMPONENTS OF THE UNDERWATER SYSTEM

These are the main components of the underwater system:

- Artificial reef
- Waterproof tank(s)
- Ropes and Nets
- UUVs
- Sound navigation and ranging (SONAR)
- Command and control station

1. Artificial Reef

The underwater system needs a component on the bottom of the sea that acts like an anchor to hold the ship after wrapping. One end of the wrapped ropes and nets must connect to this underwater structure. This structure must be heavy enough to hold the ship securely. For the most probable scenario, the structure must be placed in the northern entrance of the Istanbul Strait to stop the sample ship. Figure 61 shows the location of the structure [101]. The closest distance between the shore and the structure is 1,100 meters [102], and the depth is about 77 meters [101].

Artificial reefs have been in use for hundreds of years providing habitat for fish and other marine life. These man-made structures are generally made of concrete, limestone, steel and plastic. In summary, the underwater structure can be designed as an artificial reef and may serve as a home to fish for long years, contributing to a sustainable fishing industry.

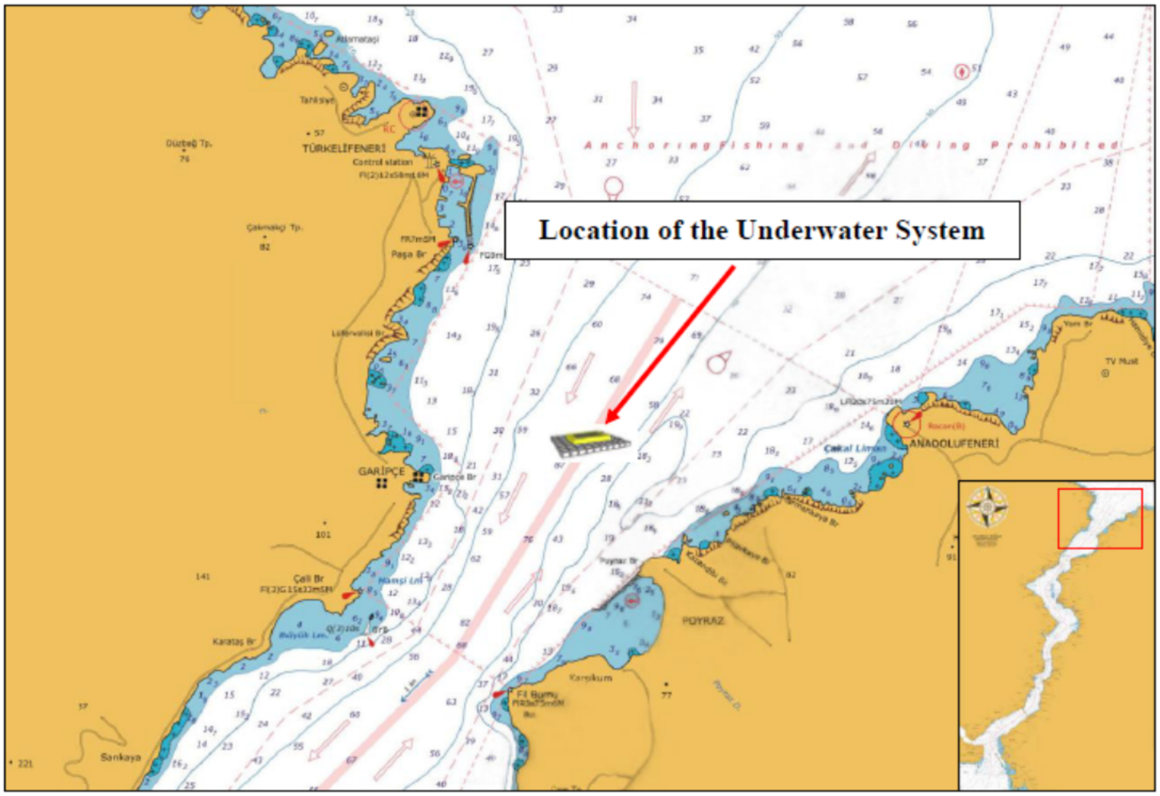

Figure 61. Location of the Underwater System (After [101])

Figure 62. Examples of Artificial Reefs (From [103], [104])

2. Waterproof Tank

The underwater system needs waterproof tank or tanks in order to store the UUVs and ropes and nets. These tanks may also contain other elements based on the details of its design. As the depth of the artificial reef is about 77 meters [101], underwater pressure is not so high, so it is possible to place waterproof tanks on the bottom of the sea. The tanks must be located on the artificial reef. Accordingly, the tanks are higher than the sea bottom and not covered with sand, and at the same time they are stable because of the weight of the artificial reef.

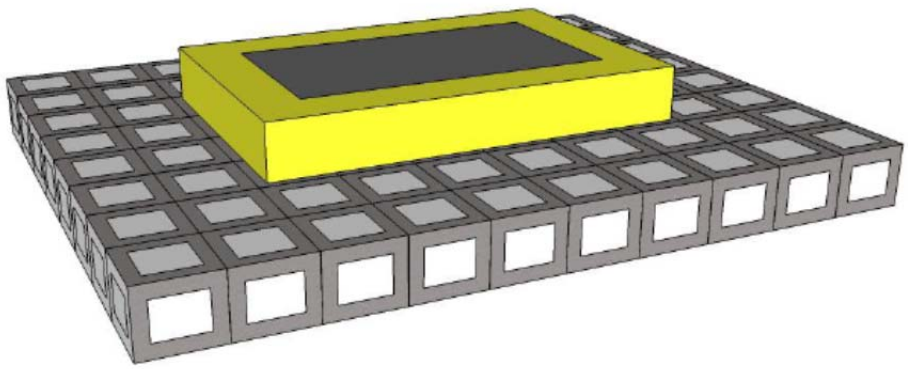

Figure 63. Sketch of the Waterproof Tank Placed on the Artificial Reef

3. Ropes and Nets

The underwater system uses ropes and nets to wrap around a propeller and its hub. There are two constraints in the selection of the ropes and nets even though these constraints do not exist in the sample ship used in this study.

First, products exist called "rope/line/net cutters," located between the propeller and the shaft and used to cut ropes, lines, and nets wrapped around the propeller [83]. Though these cutters are not commonly in use, their effects must be considered.

Second, ducted propellers (also known as Kort Nozzles) are in use to increase the efficiency of heavily loaded propellers [105]. Their design may affect the selection of the ropes and nets.

Figure 64. Examples of a Rope Cutter and a Ducted Propeller (From [106], [107])

It is easier to wrap nets around the propeller and hub than ropes because the nets are lighter and cover a wider area. The UUVs throw the nets, which are connected to ropes, and the nets wrap around the propeller and hub first. The ropes will be wrapped later as the shaft and propeller rotate. Small plastic floats can be used to increase the buoyancy of the ropes and nets, minimizing the power required for the UUVs. In all cases, the material selections of the ropes and nets are critical: high elasticity and toughness are required. The selection of the specific material is outside of the scope of this research.

Figure 65. Examples of Rope and Net with Small Plastic Floats (From [108], [109])

The system is designed to reduce the tension in the ropes after wrapping. If the wrapping begins before the ship passes above the artificial reef, it will be possible to complete wrapping and impede the propeller efficiency without applying excessive tension in ropes. The underwater system contains tensiometers for measuring the tension of the ropes. The ropes continuously will be released from the waterproof tank until the tension gets in the working limits of the ropes. Then the ropes will hold the ship like an anchor chain. As calculated in Chapter VI, and accounting for average current speed, the maximum speed of the sample ship will be approximately 2 knots after successful wrapping. In conclusion, the maximum tension in the ropes will occur when the wrapping is complete and the ship has reduced speed.

Figure 66. Minimizing the Tension in Ropes by Earlier Wrapping

4. Unmanned Underwater Vehicles

The underwater system needs UUVs to carry and throw the ropes and nets. There are two UUVs in this design, each of which has a mechanism for throwing ropes and nets. One of the UUVs throws the ropes and nets to the shaft and propeller hub while the other throws them to the propeller. The throwing time can be adjusted based on analyses of the propeller's acoustic radiation. As mentioned above, the U.S. Coast Guard uses a system for stopping a small boat's propeller called a boat trap [41], the principle of which is using ballistic nets dropped from a helicopter. The nets wrap around the propeller of the terrorist boat. The ballistic mechanism of the boat trap is activated before it hits the sea surface, so that the nets cover a wide area. The system was tested so many times in 2005, stopping 100% of small boat targets [40]. The throwing mechanism of the UUVs in this study can be designed similar to the boat trap.

The UUVs must have a system to track the position of the propeller. Therefore, there is need for sonar devices and sonar data processing. Sonar can be located in the UUVs or the UUVs can be guided with an underwater positioning, sensing, command and control system. Using sonar the UUVs get close to the terrorist ship, launch the ropes and nets at the propeller, and then retreat from the propeller. In all these steps, the UUVs use batteries for power supply. In the design, a cable line from a land-based power station to the waterproof tank keeps the batteries of the UUVs fully charged.

Figure 67. REMUS 6000 Equipped with Sonar (From [110])

5. Sonar

The underwater system needs sonar to detect, classify, localize and track the propeller of the terrorist ship. The word sonar comes from “SOund NAvigation and Ranging.” R.P. Hodges [111] reports:

> The operation of sonar is based on the propagation of waves between a target and a receiver. The two most common types of sonar systems are passive and active. In a passive sonar system, energy originates at a target

> and propagates to a receiver, analogous to passive infrared detection. In an active sonar system, waves propagate from a transmitter to a target and back to receiver, analogous to pulse-echo radar…. The noise radiated from propellers is different from internal machinery noise in that it is outside the ship and in direct contact with the medium.

R.D. Collier [112] reports:

> The four principal groups of radiated noise sources are (1) machinery vibration caused by propulsion machinery and ship's services and auxiliary machinery, including steam, water, and hydraulic piping systems; (2) propellers, jets, and other forms of in-water propulsion; (3) acoustic noise within compartments below waterline; and (4) hydroacoustic noise generated external to the hull by flow interaction with appendages, cavities, and other discontinuities."

All of these sources have different frequencies in noise spectra.

The propeller noise can be divided into two groups, cavitating and noncavitating. D.T. Blackstock and M.J. Crocker [113] report,

> Cavitation can occur in fluids because of variety of causes, one of which is acoustic excitation. If sufficiently intense sound fields are created in a liquid, then cavitation can occur during the low-pressure phase of the pressure fluctuations when bubbles are produced. Strong noise occurs during acoustic cavitation. It is caused by the cavities or bubbles which are generated and set into oscillation in the sound field.
>
> R.D. Collier [112] reports:
>
> There are three types of noncavitating propeller noise: (a) mechanical blade tonals related to propeller shaft speed and the number of blades; (b) propeller broadband noise related to blade vibratory response to turbulence ingestation and trailing-edge vortices; (c) propeller singing due to coincidence of vortex shedding and blade resonant frequencies.

In conclusion, the working principle of the underwater system is based on tracking propeller noise, and it is possible to detect, classify, localize and track propeller noise by using sonar. In the design, there is a network of active and passive sonars.

6. Command and Control Station

There must be a land-based command and control station to activate and control the underwater system via underwater positioning, communication, sonar data processing. This station also provides power to the waterproof tanks and the batteries of the UUVs by cables. The station must be employed under the authority of the Turkish Coast Guard Command.

B. PROBABLE MOTIONS OF THE SHIP AFTER WRAPPING

It is not possible to understand the exact motions of the ship after successful wrapping because of the random nature of the wrapping. On the other hand, it is possible to make some estimation based on assumptions.

1. Assumptions

a. The Loss of Efficiency Assumptions

In Chapter VI, three different cases were used to demonstrate the loss of efficiency caused by the increase in hub diameter. In this chapter, Case 2 is selected to estimate the motions. Here is the list of the assumptions based on the calculations in Chapter VI.

- The propeller diameter: 2.5 meters
- The initial hub diameter: 0.4 meters
- Rotation speed: 150 rpm
- The diameter of the hub will be at least three-fourths of the propeller diameter at end of the wrapping. Therefore, the loss of efficiency will be 50%, caused by the increase in hub diameter.
- There will be 45% loss of efficiency because of the increase in the design blade thickness, blade area, roughness, appendage resistance and other effects of wrapping.
- The total loss of efficiency will be 95% after wrapping, 50% from the increase of hub diameter and 45% from changes in the blade thickness, area, and roughness, as well as other effects.

- Because of the random nature of the wrapping, it is assumed that the loss of efficiency caused by changes in the blade thickness, area, and roughness as well as other effects are linearly proportional to the loss of efficiency caused by increase of hub diameter.

b. Increase of Hub Diameter Assumptions

Here is the list of the assumptions about the increase of hub diameter:

- The diameter of the hub will be 1.88 m (¾ of the propeller diameter) after wrapping.
- There is a 1-meter-long clearance between the propeller and the ship's hull. Therefore, the rope will be wrapped around this 1-meter-long shaft/hub.
- In normal cases, the wrapped rope will be closer to the propeller, away from the ship's hull, because of the forward motion of the ship. In this calculation, the wrapping of the rope around the propeller hub/shaft (1-meter-long clearance) is assumed to be rectangular pattern (when viewed from the port/starboard side, the wrapped-rope has a rectangular cross-sectional area). This is the worst-case scenario because in this case it will take a longer time to increase the hub diameter. For example, if the diameter of the rope is 5 cm, the propeller/shaft must rotate 20 cycles to cover the first row of the 1-meter-long clearance, after which the wrapping of the second row will begin, and the hub radius will increase 5 cm more. This process continues until the ship stops.
- There will be no decrease in the diameter of the rope during wrapping because of compression/squeezing.
- The volume of small plastic floats, used to increase the buoyancy of the ropes and nets, is ignored.
- First, the nets will be wrapped; the ropes will begin to wrap 5 seconds later.

c. *Other Assumptions*

- The rotation speed of the shaft will be constant during wrapping.
- The motion of the ship will always be in the forward direction. The course of the ship will not change during wrapping.
- The ropes will not be deformed during wrapping or at the time of stopping.
- The weight of the artificial reef is enough stop and hold the ship.
- The ropes continuously will be released from the waterproof tank until the tension gets in the working limits of the ropes.

2. Results

Four different rope diameters (3, 4, 5 and 6 cm) are selected for the motion calculations. Based on the above assumptions, the distance traveled and the changes in speed of the ship are calculated. Figure 68 demonstrates the relation between the rope diameter and the distance traveled. These are the traveled distances of the ship until the efficiency loss becomes 95%. After this point, the ship will continue to cruise until the releasing of the ropes is stopped, e.g., when the tension in ropes gets in the working limits. Therefore, the total stopping distance (not calculated) of the ship will be greater.

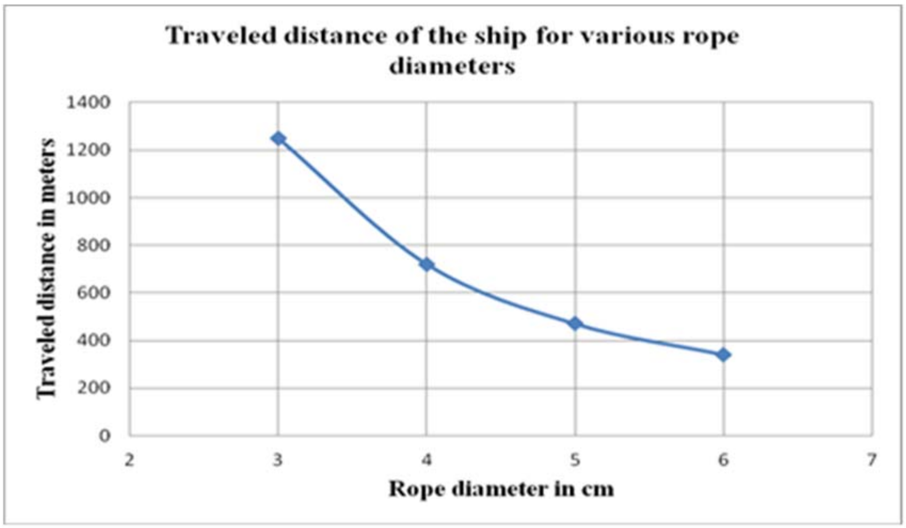

Figure 68. Traveled Distance of the Ship for 95% Loss of Efficiency

In this design, the selected rope diameter is 5 cm. Figure 69 shows the total traveled distance (470 meters) for 95% loss of efficiency for the 5 cm rope diameter.

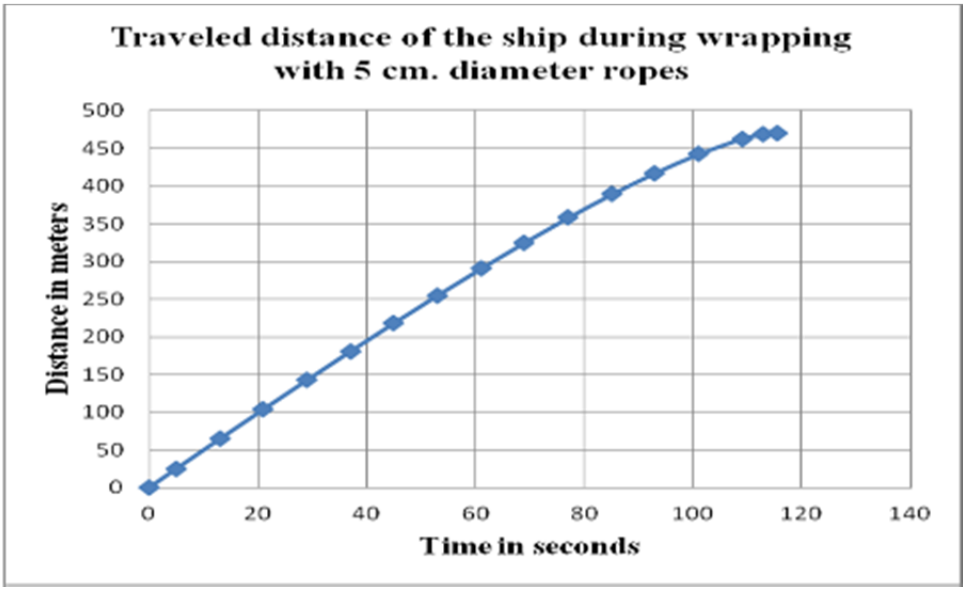

Figure 69. Traveled Distance of the Ship for 5 cm Rope Diameter

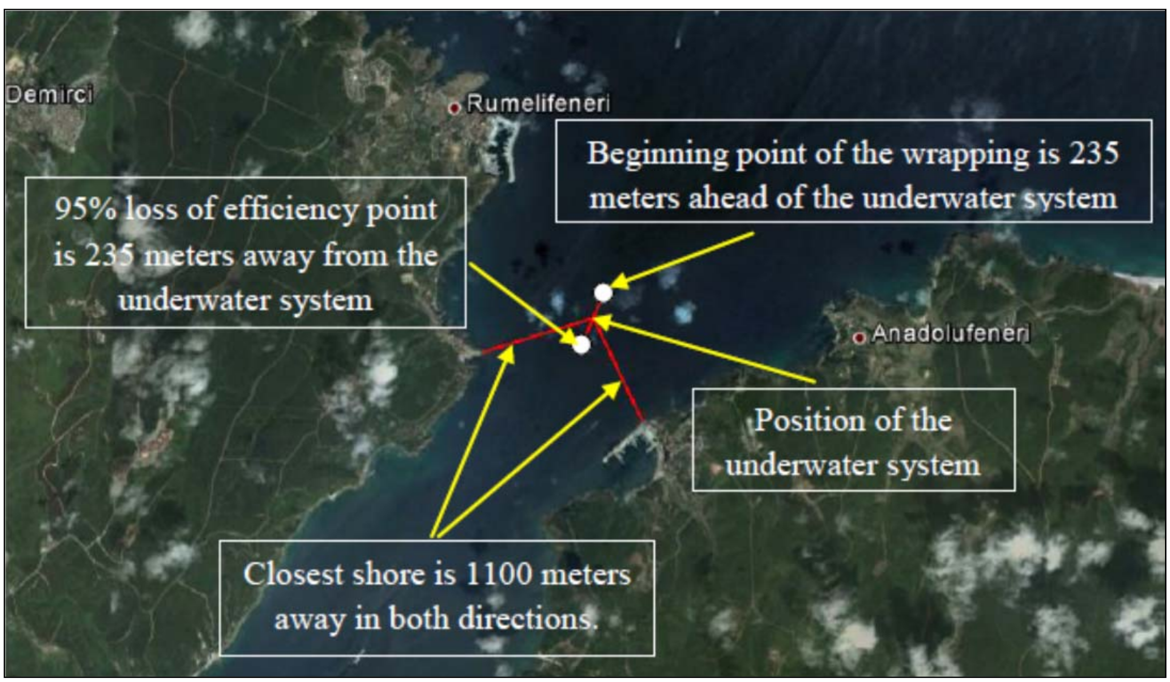

Figure 70. System's Geographical Summary for 5 cm Rope Diameter (After [102])

These graphs show the change of speed, based on the thrust produced, during wrapping with the 5-cm-diameter rope:

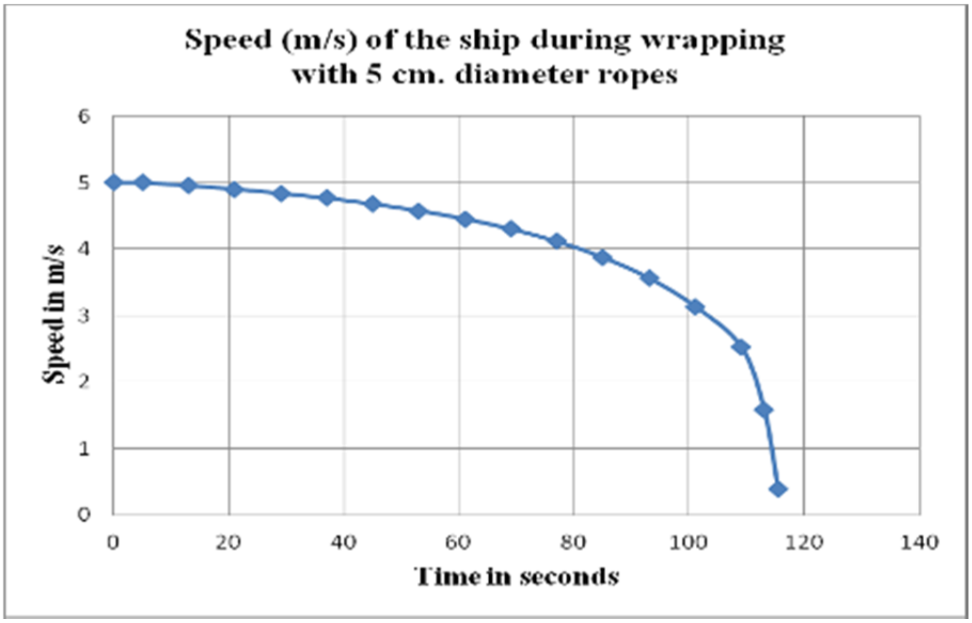

Figure 71. Change of Speed (m/s) for 5-cm-diameter Rope

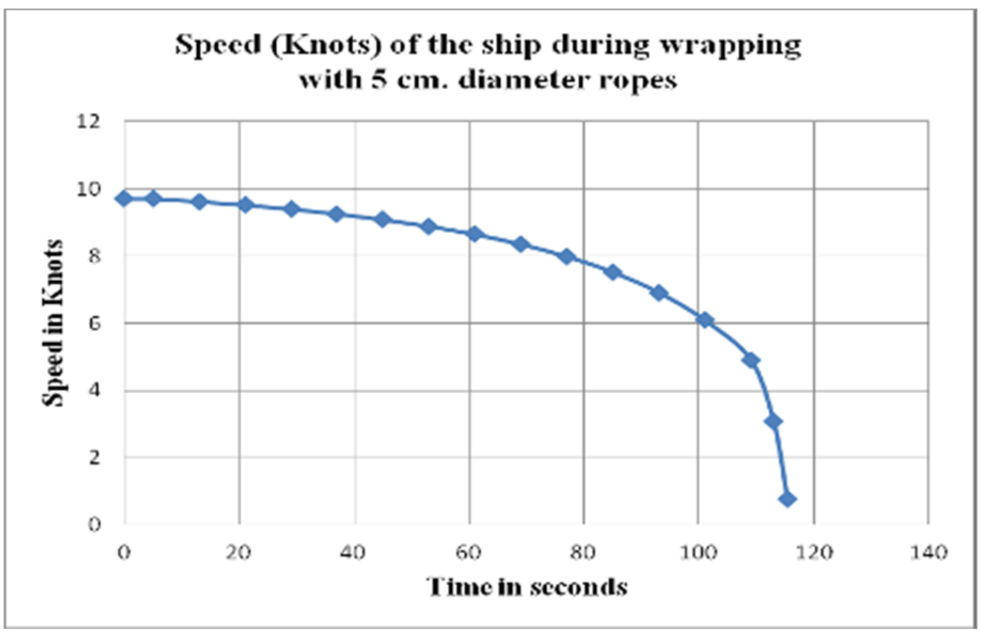

Figure 72. Change of Speed (knots) for 5-cm-diameter Rope

C. SKETCHES OF THE UNDERWATER SYSTEM FOR THE MOST PROBABLE SCENARIO

Figure 73. The LPG tanker under the control of terrorists is cruising towards the northern entrance of the Istanbul Strait, and the command and control station is ready to activate the underwater system.

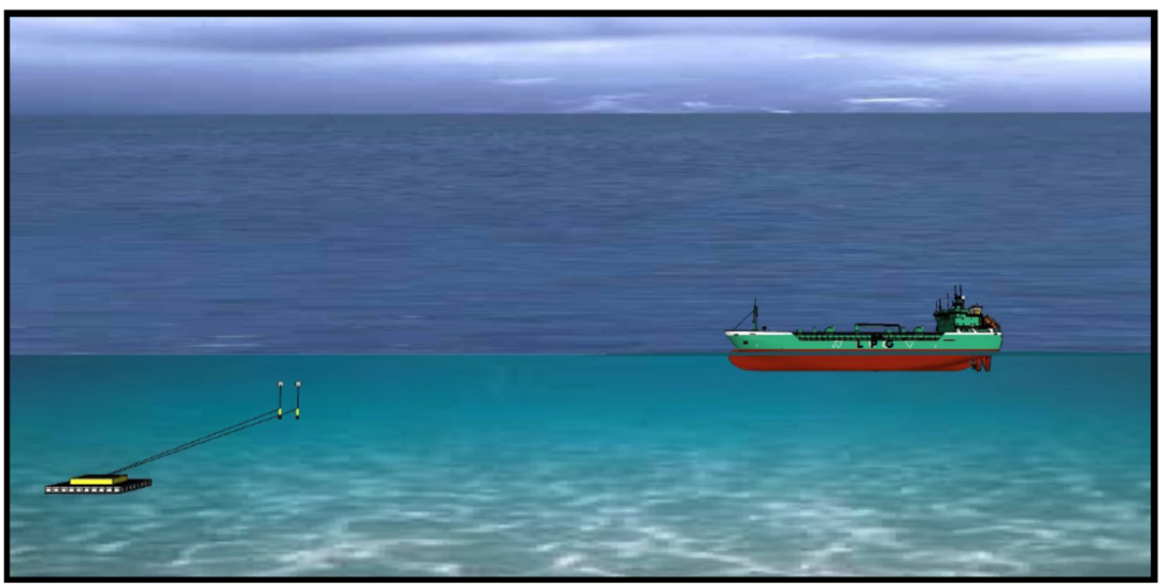

Figure 74. The underwater system is activated, the waterproof tank is opened and the UUVs are released. The UUVs carry the ropes and nets to the propeller of the ship using sonar data.

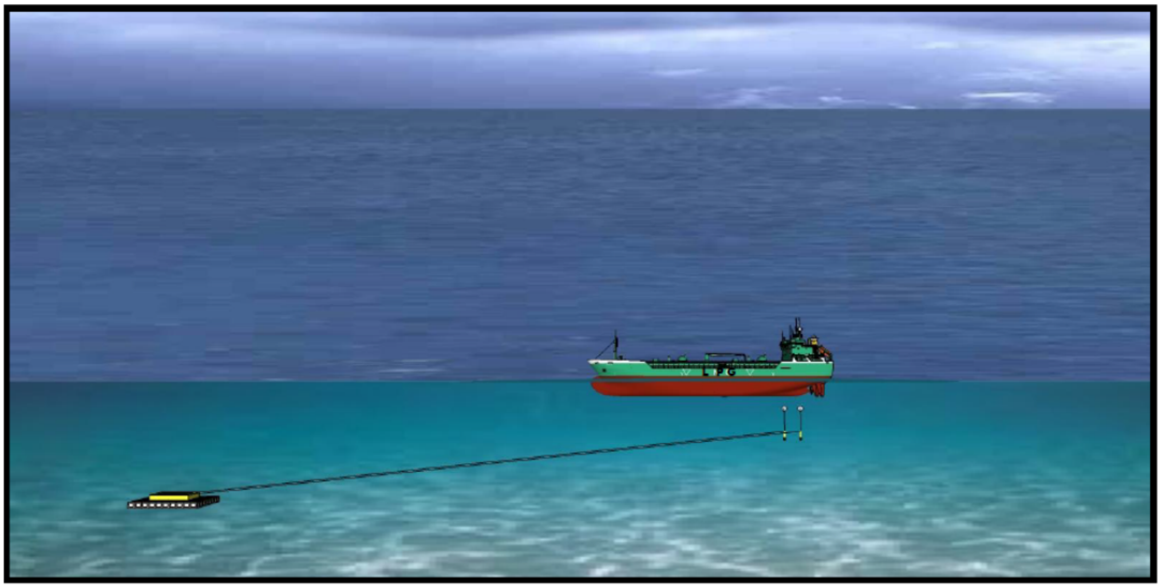

Figure 75. The UUVs are ready to throw the nets using the launching mechanism.

Figure 76. The UUVs launch the nets, are released from the ropes and retreat from the propeller. The ropes are about to wrap around the propeller and its hub.

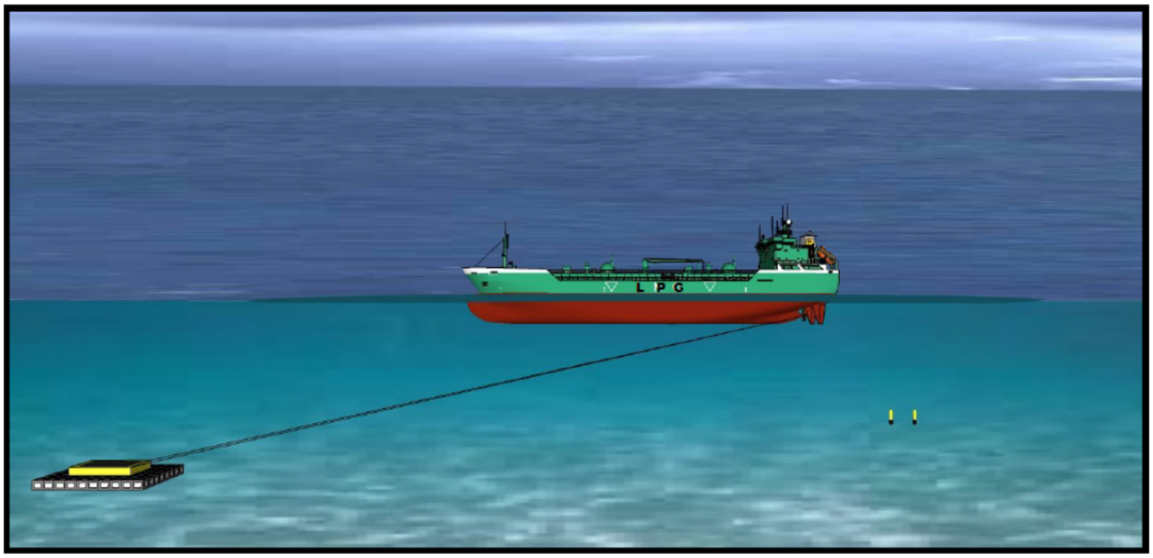

Figure 77. The ropes are wrapped, and the UUVs are away from the propeller. Propeller efficiency begins to decrease.

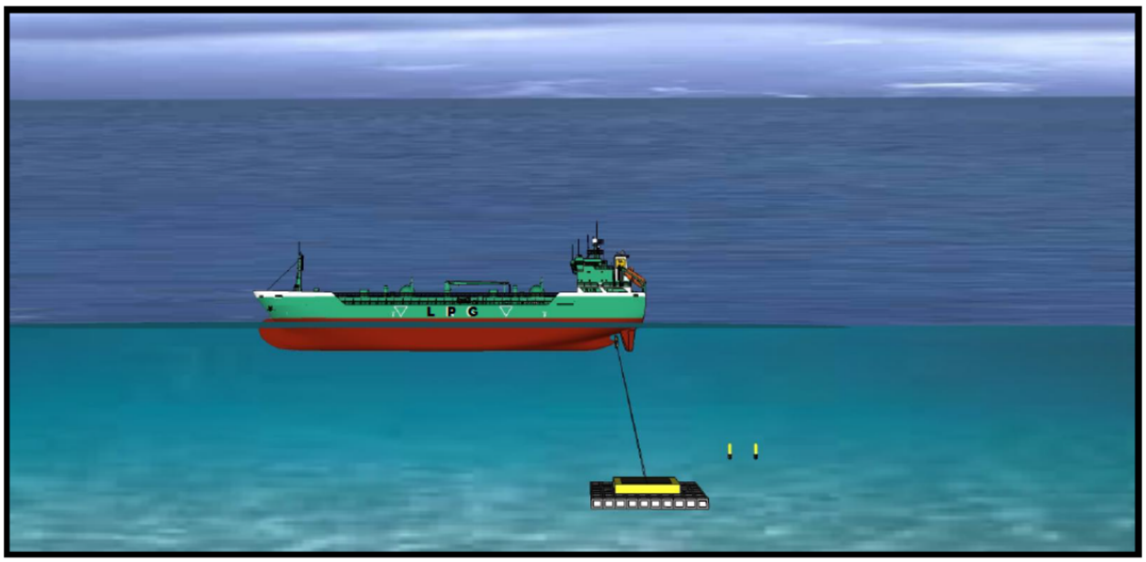

Figure 78. The propeller efficiency continues to decrease, and the ship slows down.

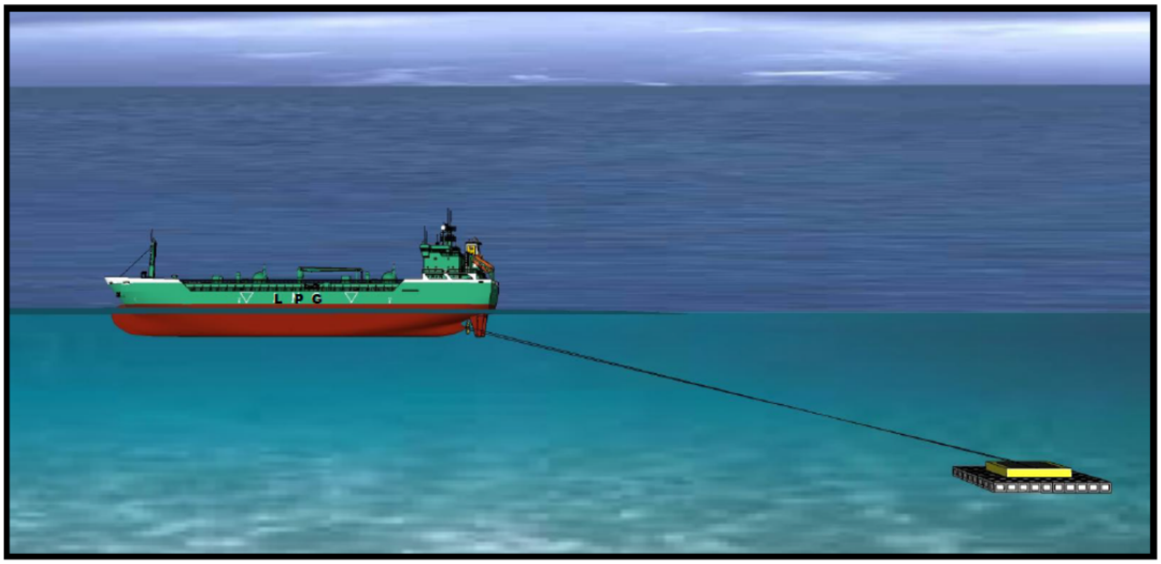

Figure 79. The speed of the ship is approximately 2 knots, and artificial reef holds the ship like an anchor. There is no excess tension in the ropes. The terrorist ship is stopped before entering the Istanbul strait.

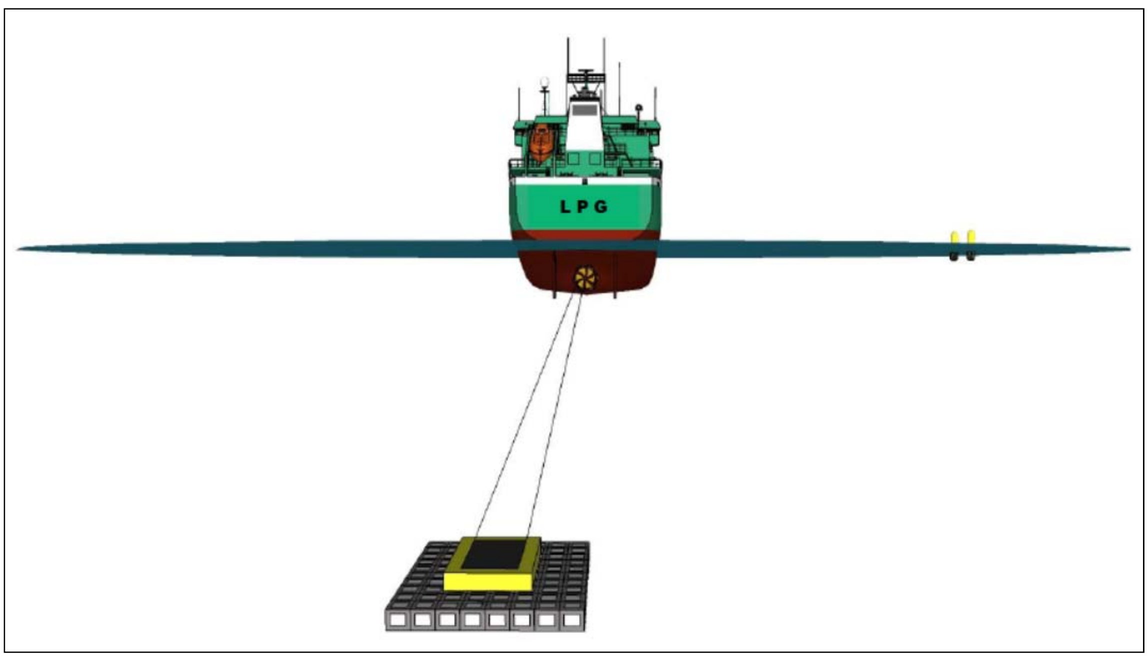

Figure 80. A sketch of the underwater system after successful wrapping

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VIII. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

This research demonstrated that the security of the Turkish Straits against maritime terrorism can be increased by designing an underwater system that can stop a terrorist ship by impeding its propeller efficiency. Protecting the Turkish Straits is an important security problem that must be solved because they are highly vulnerable to terrorist attacks. It is relatively easy to execute a terrorist attack in the straits because of the intense maritime traffic, narrow geographical configurations and high population density. Terrorists do not need a high amount of explosives because the cargo of Liquefied Natural Gas (LNG), Liquefied Petroleum Gas (LPG) and other chemical carrying ships is itself highly explosive. An explosion in the straits may cause the loss of thousands of lives, an environmental catastrophe, closure of the straits for navigation and an economic crisis.

First, the most probable scenario from the point of view of a terrorist organization was determined based on the information and analysis in Chapters II, III, IV and V. According to this analysis, the most likely scenario is a conspiracy of crew members aboard an LPG carrier, using a vessel in the Istanbul Strait to carry out a terrorist attack.

Second, all the existing and some non-existent methods to prevent this scenario were analyzed; Table 6 shows these 20 methods. Table 13 summarizes that existing methods currently provide no absolute protection against the most probable scenario. Therefore, a new system was designed after studying currently non-existent methods. Based on the analysis in Chapter VI, the most applicable and feasible non-existent method was selected. The method of protection selected was stopping the propeller.

Finally, an underwater system was designed to impede the propeller efficiency of a ship by wrapping ropes and nets around the propeller and its hub, stopping the ship before entering the strait. These factors would decrease the propeller’s efficiency and increase resistance after wrapping:

- An increase in the hub diameter,

- An increase in the thickness of the blades (blade thickness fraction),
- An increase in the blade area,
- An increase in the roughness (surface friction of the blades) and
- Other effects, for example increased appendage resistance, friction on shaft and change in the flow characteristics.

Computational methods (OpenProp v2.4.6) and experimental results of previous researchers were used to demonstrate the loss of propeller efficiency after wrapping. The results in Chapter VI demonstrate that the loss of efficiency will be greater than 90% after successful wrapping. Calculations of "efficiency loss" and "probable motions of the ship after wrapping" show that it is possible to stop the terrorist ship before entering the strait.

The working principle of the underwater system was based on tracking the acoustic radiation of the propeller. The main components of the underwater system are an artificial reef, waterproof tank(s), ropes and nets, unmanned underwater vehicles (UUVs), sound navigation and ranging (SONAR) and a command and control station.

With such an underwater system, it is possible to stop the terrorist ship before it enters the straits and prevent further damage it may cause. The underwater system will provide an alternative and non-lethal solution in addition to existing methods. It may serve as a deterrent to terrorists, forcing them to change their plans. The underwater system also can be used to protect shore facilities and harbors against maritime terrorism. Finally, it can be used in wartime scenarios against enemy warships.

B. RECOMMENDATIONS

This research demonstrated that there is no absolute protection against the most probable maritime terrorism scenario using currently existing methods and aimed to design a new system to increase the security of the Turkish Straits. Chapters II, III, IV and V sought to answer the questions of "why" and "what" is needed. Therefore, only Chapters VI and VII studied "how" the new system would work. Time constraints of this research limited studying the details of the underwater system, such as the effects of wrapping patterns, power requirements, acoustics and the material selection.

Because there was no opportunity to conduct experiments in this research, OpenProp v2.4.6 software was used to calculate the efficiency loss due to the increase of hub diameter after wrapping. The efficiency loss caused by the other factors (i.e., an increase of the propeller blade thickness, blade area, roughness and appendage resistance) can also be calculated using computational methods despite the random nature of the wrapping. However, because of time limitations, a computational method was not used to calculate the efficiency loss due to these factors.

The OpenProp v2.4.6 creates an output file that has all the geometrical information of the designed propeller blade. Using this file, it is easy to create a solid blade in SolidWorks software. After creating of the solid blade in SolidWorks, the blade can be opened with the ANSYS software. Figures 57, 58 and 59 show these steps. Both in SolidWorks and in ANSYS, the whole propeller and the ropes or nets wrapped around the propeller can be drawn. After that, the flow around the propeller and wrapped ropes or nets can be defined in ANSYS. In this way, the wrapping can be simulated, and the propeller efficiency after wrapping can be calculated using the CFD codes of ANSYS. However, because of the random nature of the wrapping, different wrapping patterns must be created to compare the results. In this research, the CFD method was not used because of time limitations. For further studies, it is recommended that computational methods be used to understand the effects of wrapping on efficiency loss.

This research described the working principle, main components and functions of the underwater system. The power requirements, weight and strength calculations, acoustics, underwater positioning methods, wrapping mechanism and the material selection were not studied because of time limitations. Further studies in these areas are recommended to complete the detailed design.

Currently, there is no LNG carrier ship traffic in the Istanbul Strait. Therefore, an LPG carrier ship was selected as the target ship in the most probable scenario. However, a typical LNG carrier ship’s cargo is 10 to 15 times larger than a typical LPG carrier ship's cargo, so the damaging effect of an LNG carrier ship explosion would be much greater than that of a LPG carrier. In the future, LNG terminals may be built in the Black Sea region, and there may be LNG carrier ship traffic in the Istanbul Strait. In this case, the most probable scenario will change. It should be noted that the different characteristics of LNG carrier ships may affect details in the design of the underwater system.

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