8-28-2016

Study on the efficacy of helicopters in the field of maritime rescue

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STUDY ON THE EFFICACY OF HELICOPTERS IN THE FIELD OF MARITIME RESCUE

By

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The People's Republic of China

A research paper submitted to the World Maritime University in partial Fulfillment of the requirements for the award of the degree of

MASTER OF SCIENCE

(MARITIEM SAFETY AND ENVIRONMENTAL MANAGEMENT)

2016

FORMAT OF THE DECLARATION

I certify that all the material in this research paper that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this research paper reflect my own personal views, and are not necessarily endorsed by the University.

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ACKNOWLEDGEMENTS

Firstly, I would like to give my sincere gratitude to the Nanhai No.1 Flying Service Team of Ministry of Transport for the valuable opportunity to take the master degree studies in Dalian Maritime University.

I also deeply appreciate the World Maritime University and Dalian Maritime University for the chance of postgraduate studies-MSc Program in Maritime Safety and Environmental Management, as well as all excellent professors and staffs. Because of their hard work, I have learnt a lot from this program.

My sincere thanks also go to my supervisor Prof. Zhu Yuzhu for his kindness, patient and professional guidance. His attitude will inspire me to do a better job in my future career and whole life. At the same time, I would like to express my appreciation to Lecturer Han for her valuable comments and suggestions.

I want to thank all my classmates of MSEM and colleagues in Nanhai No.1 Flying Service Team for their support and encouragement, which have been a great memory and a great source of confidence to accompany my postgraduate studies.

Last but not least, I am everlastingly grateful to my beloved parents who are always giving their full support whenever I need. The success and achievement which I made during my studies in the MSEM would not have come true without their never-ending encouragement.

ABSTRACT

Title of Research Paper: **Study on the Efficacy of Helicopters in the Field of Maritime Rescue**

Degree: **MSc**

Since the international trade is increasing gradually, more and more ships are involved in the marine transportation. The situation highly threatens the safety of shipping. As a matter of fact, the number of serious maritime accident has kept growing.

The question is how to prevent accidents from happening and to reduce its damage. The national search and rescue team is built to solve those problems. There is no doubt that each national SAR team will save people, property in distress as soon as possible, because time is limited in the rescue operation.

Therefore, it is significantly important for SAR team to find a flexible vehicle to deal with all urgent situations. All of USCG, JCG and CRS have used helicopters as their main rescuing force, because it can adapt new environment quickly. Meanwhile, using helicopters in maritime rescue operation will increase the efficiency of rescuing activity. The efficacy of helicopter in maritime rescue operation should not be ignored.

KEY WORDS: USCG, JCG, CRS, urgent situation, helicopter, efficiency

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LIST OF ABBREVIATIONS

U.S.	United States
USCG	United States Coast Guard
JCG	Japan Coast Guard
CRS	China Rescue and Salvage
EEZ	Exclusive Economic Zone
VTOL	Vertical Take-off and Landing
IAMSAR	International Aeronautical and Maritime Search and Rescue
HKGFS	Hong Kong Government Flying Service
BHA	British Helicopter Association

CHAPTER 1

INTRODUCTION

1.1 Search and rescue background

With respect to search and rescue operations in general terms, the probability of occurrence of a large-scale rescue is not high. However, worldwide large-scale maritime rescue operations have occurred frequently in recent years. As a matter of fact, huge losses will be incurred by the impact of main shipwreck. Dealing with large-scale rescue operation as well as establishing a maritime emergency rescue system is critical for every maritime state. Therefore, professional rescue and salvage force plays an important role in national emergency security system. At the same time, the force will be in charge of handling serious maritime accidents. With the sustainable economic development of China, a serious of maritime industries, including maritime transport, offshore oil and gas industry, naval architecture, offshore tourism and fishing, have been increasingly promoted. Due to the development of maritime industry, the number of ships and seafarers has also increased. According to the research by Wang (2015), the total number of Chinese seafarers has reached 603,622 by the end of 2014. Consequently, the number of maritime accident keeps growing. Rescue and salvage force, the main strength to safeguard maritime safety, exerts positive influence on protecting lives and property

at sea.

To protect the lives, property and environment along the 18,000 km coastline and on 3 million square kilometers of sea, China has initially established offshore emergency rescue system, in which helicopter has played a key role. In China's rescue system, rescue helicopter is responsible for search and rescuing lives in distress, emergency evacuation, transportation and other important task, so it occupies a commanding position. The rescue helicopter of China has repeatedly joined in large-scale rescue operations at sea and has participated in international joint search and rescue operations. For example, China has sent search and rescue team to search for MH370. From the perspective of state's liability and public expectation, after "Malaysia Airlines incident", it is necessary to have a helicopter team in national rescue system. China has set up four Flying Service teams with a total of 20 helicopters. In contrast with developed countries, the total number of helicopter is not enough to cover whole sea area.

Clearly, adequate preparedness and rapid response jointly contribute to a successful conduct of effective protection of large-scale operations. There is no doubt that helicopter will be suitable for those requirements. Moreover, China should foster its own search and rescue team. However, the question is why helicopters is our main focus, in spito of our adequate vessels in hand. Chinese rescue organization also has adequately prepared vessels. In this research paper, the author will take the opportunity to concentrate on the efficacy of helicopter in the field of maritime rescue. It is going to elaborate on the prospect of helicopter will be the main rescue vehicle in the future.

1.2 Objectives of research

The primary purpose of this research paper is to verify that helicopter rescue operations are the most effective method. Therefore, it needs to prove the indispensability of helicopter in national rescue system. Furthermore, it can demonstrate the helicopter's efficiency by listing its advantages.

1.3 Methodology

By comparing with developed countries' search and rescue system, the paper will reflect the leading role of helicopter in the national rescue system. Meanwhile, the establishment of the optimized model-maritime search and rescue is to prove that the efficiency of the aircraft is the foremost.

1.4 Structure of the research paper

The research paper consists of 6 chapters. Chapter Two describes the national rescue system of the United States, Japan and China, but it mainly focus on the comparison of rescue system among three countries. To find out similarities and differences, the contrast can verify that the helicopter in rescue system is indispensible. Chapter Three describes the main search and rescue aircraft's functions and effects, presenting the practical efficacy of helicopter. Chapter Four provides an optimized diorama on maritime search and rescue to testify the efficiency of helicopter. Chapter Five structures an overview of improvements in rescue helicopter. Finally, the last chapter comes to overall conclusions and summaries.

CHAPTER 2

National rescue system among the United States, Japan and China

2.1 Introductory remarks

In terms of the efficacy of helicopters in the field of rescue, it is necessary to understand the process of the operation in a rescue organization, for the process helps people understand the position of helicopter in the rescue organization and its relation with other departments. This chapter is going to discuss three rescue organizations of United State, Japan and China respectively. United State possesses one of the most developed rescue system in the world; Japan also has an experienced rescue team and a quick response rescue system; China's rescue organization which has been the latest founded among the three organizations has gained good experience from other developed countries. Although the following paragraph shows that three organizations have differences, it is important for readers to realize that their common areas are essential for rescue.

2.2 United State Coast Guard

The coastline of United States (including Alaska) has extended approximately 19924 kilometers, covering the Atlantic, the Pacific, the Gulf of Mexico and the five Great Lakes in the North America. U.S. maritime search and rescue area which mainly

focuses on the water area of the Pacific and the Atlantic is very broad. The actual coverage of U.S. maritime search and rescue region is shown in Figure 1.

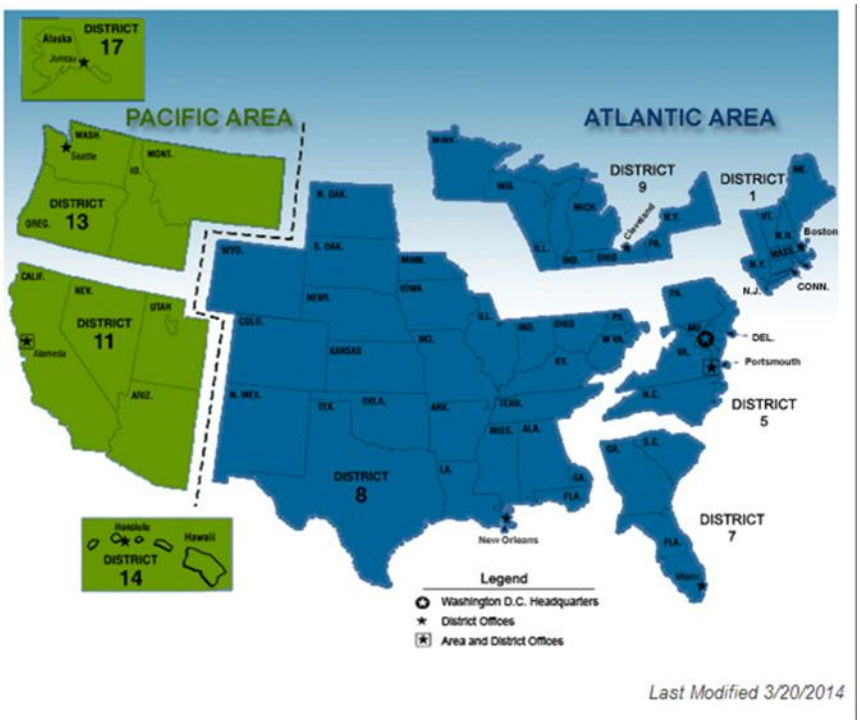


Figure 1 USCG distribution of coverage

Source: *Units* [imagine]. (2014). Retrieved from http://www.uscg.mil/top/units/

In order to strengthen international cooperation in maritime search and rescue, United States has signed a cooperative agreement or memorandum of cooperation with many countries that share the same search and rescue zone. In United States, there are four types of search and rescue work, which includes city, e.g. Collapse of building, water, inland and air search and rescue (Zhang, & Zhang, 2011). Firstly, Federal Emergency Management Agency which belongs to Department of Homeland Security is responsible for the city search and rescue. Secondly, the duty of water search and rescue is taken care by United States Coast Guard. Moreover, National Park Service, a branch in the Department of the Interior, pays attention on the inland search and rescue operation. Finally, the air search and rescue relies on United States Air Force from the Department of Defense.

This paper is going to discuss maritime search and rescue, so the following paragraph mainly focus on USCG. USCG is the main force in the maritime search and rescue. According to statistics (Chen, & Yang 2008, p.231-232), USCG has succored a total of approximate 1109000 people out of danger since it was founded in 1970. Its success could not be achieved without its advanced search and rescue equipment and facilities can work effectively. USCG has considerable boats and planes, so it is important for USCG to establish an effective system under which plane, boats and shore-based facilities. As a matter of fact, USCG has made a good combination between search and rescue and safe cruising.

2.2.1 Planes and Facilities of USCG

USCG has been equipped with a lot of aircrafts for cruising to ensure that there is always a quick response team for any distress. The following list is the overview of the plane:

1. There are 26 long-range fixed-wing search aeroplanes (HC-130). Their maximum cruising range is 4,500 nm.
2. The fixed-wing aircraft (HU-25) is of 1,700 nm cruising range. USCG owns 21 HU-25 planes for its middle range search operation.
3. There are 42 middle range helicopters (HH-60) with a maximum cruising range of 700 nm, which is shown in the Figure 2. The main role of HH-60 which can carry 12 people in maximum is for middle range rescue operation.

Figure 2 - HH-60J rescue operation

Source: *HH-60J* [Imagine]. (2013). Retrieved from http://www.usnook.com/military/aircraft/helicopter/2013/0930/64015.html

4. The number of short range helicopter (HH-65) is 102, and it has 375 nm maximum cruising range. The flight is responsible for the quick response rescue operation.

5. USCG owns 6 tactical transport planes (C-130J) with the maximum cruising range of 5500 nm.

In order to get these aircrafts to effectively involved in the maritime search and rescue operation, USCG headquarter has set up one aviation management organization and 26 air bases.

2.2.2 USCG water rescue facilities

USCG not only has planes for quick response rescue, but also uses boats as its main rescue force. USCG is equipped with different kinds of ships, which are mainly divided into two categories: large cruisers (cutter) and small cruisers (boat). According to the length of the ship, for the measure is simple and commonly used.

1. Large ships that refer to the length of the ship at 65 feet and above should have enough space for crew on board. At present, USCG has 247 large ships, including icebreakers, cruisers, stake boats, tugboats and supply ships. These ships with 180 feet and above are controlled by the regional headquarters' (Pacific or Atlantic region) command. Vessels within 180 feet in length will follow the command of regional headquarters. These large ships are usually equipped with high-speed motor boats, so large ships can send small boats to save people under mishaps.

2. Small vessels refer to the length that is less than 65 feet. USCG now has more than 1,850 small ships, which are mainly used in offshore or the inland river tasks. These vessels cover motor lifeboats (within 52, 47 or 44 feet), speed and multi-purpose ships (within 41 feet), rescue ships, port security ships (within 25 feet), assistant navigation ships (21 ~ 64 feet), and other small non-standard ships.

The principal foundation of air base is based on densely populated areas and other areas where accident frequently happen, so air base is usually set up near ports, fishing areas, recreation areas. The distance among each base is between 200 nm to 500 nm. According to research paper (Chen & Yang 2008, p.231-232), each base owns different quantity of helicopters and fixed-wing aircrafts to meet local task requirements. Moreover, the number of helicopters in each base cannot be less than 3 flights. One helicopter will be primarily responsible for search and rescue duty; one will undertake the duty of training mission and backup flight; the last one will be

arranged into repair and maintenance. The whole shift system ensures that there will be a good condition of search and rescue planes on duty. As the paper (Chen & Yang 2008, p.231-232) shows that the helicopter is the first choice of the U.S. maritime search and rescue operation. Since U.S. helicopters are required to arrive at the spot in less than 2 hours, it greatly improves the possibility of surviving lives at sea.

2.3 Japan Coast Guard

According to JCG's pamphlet (2015), Japan has spent a lot of resources on maritime management, for its size of territorial sea and exclusive economic zone of Japan (4,470,000km^2) is much larger than its inland area (380,000 km^2) which only ranks at 61st in the world. Moreover, the Government of Japan has signed an agreement with the Government of the United States of American in December 1986 on Maritime Search and Rescue. The agreement stipulates that Japan is in charge of coordinating search and rescue activities that extends northward from 17 °North and westward from 165 °East (Japan annual report). Since Japan has a huge expanse of ocean, it not only enjoys the benefits of the sea from maritime trade or fishing, but also from plagued by maritime accidents, smuggling and illegal migration. To protect such expanse of ocean, the Japan Coast Guard has been established in May 1948. JCG is required to get involved in the whole day activities, including search and rescue work, maritime environmental protection, maritime safety operations and so on. In the meantime, JCG is responsible for improving collaboration and cooperation with other countries.

JCG is composed of headquarters and branch. JCG's headquarters, located in Tokyo, has a total of five functional departments, including Administration Department, Equipment and Technology Department, Guard and Rescue Department,

Hydrographic and Oceanographic Department and Maritime Traffic Department, as well as two schools which are Coast Guard Academy and Coast Guard School respectively. In the meantime, the whole country has been divided into 11 regions by the JCG, so it can improves the efficiency of coast guard operations. There are 70 Coast Guard Offices, 2 Coast Guard Air Stations, 61 Coast Guard Stations, 7 Vessel traffic service centers and 12 Air Stations under the structure of JCG's Regional Coast Guard HQs. Also, the Regional Coast HQs has Transnational Organized Crime Strike Force Station, Special Security Station, National Strike Team Station and Hydrographic Observatory following its command. All these units facilitate JCG a strict organization and almost cover all aspects of maritime problems.

Figure 3-Headquarters and Branches of JCG's distribution.

Source: Japan Coast Guard. (2015). *JCG - Keeping the oceans safe and enjoyable for future generations!*. Retrieved from http://www.kaiho.mlit.go.jp/e/index_e.htm

JCG's Guard and Rescue Department is in charge of Japan's maritime search and rescue work. In order to better deal with all kinds of marine accidents, JCG constantly spends a lot of time and resources in updating search and rescue equipment and improving rescue technology. At the same time, JCG has arranged the staffs of Guard and Rescue Department to promote their professional rescue skills and has enhanced the cooperation with domestic rescue departments, social organizations and neighboring countries.

2.3.1 JCG Planes and facilities

JCG has been equipped with a variety of flights, so its planes can be responsible for every kind of mission such as transportation, maritime reconnaissance and search and rescue. The list of planes will be shown as follows:

1 JCG owns two kinds of tactical transportation areoplanes that are originally designed for passenger transport, but JCG favors their ability of long range reconnaissance and search and their refitting ability. Gulfstream V and Falcon 900 are the two long range flights, with flying range of 6,500nm and 3,995 nm respectively, that JCG has bought 2 for each type

2 There are 22 long range fixed-wing flights in service. Their maximum range is from 800 nm to 1,000 nm. The majority of long range fixed-wing planes are turboprop aircrafts, so the speed is much lower than that of the tactical flights. JCG has three types of turboprop aircrafts, including Bombardier 300, Saab 340 and Beechcraft 350. The long range flights will be relied on in a more careful search mission.

3 There are 48 helicopters, from large size (Super Puma 225) to small size (Bell 206), under JCG's command. Although their longest range is only 463nm, it is easy for helicopters to get closed to ships in distress, for helicopters can hover on the top of the ship. Helicopters are the main force to rescue people at sea in danger.

Figure 4-JCG's Super Puma 225

Source: *MH687* [Imagine]. (2016). Retrieved from http://www.kaiho.mlit.go.jp/soubi-yosan/soshiki/air/mh687.jpg

2.3.2 JCG water facilities

The vessels of JCG are not only in charge of search and rescue, but also take charge of criminal investigation and maritime security operations. Due to the purpose of those ships, vessels have been divided into 6 types by JCG, including Patrol Vessels, Patrol Craft, Special Guard and Rescue Crafts, Hydrographic Survey Vessels, Lighthouse Tenders and Training Boats. According to the Table 1, approximately 80% of the vessels in JCG belong to Patrol Vessels that mainly work for the protection of sovereignty and the duty of maritime police under the Maritime Law of Japan.

Table-1 Quantity and percentage for each JCG's kind of ship

JCG	Quantity	Percentage
Patrol Vessels	366	80.4%
Special Guard and Rescue Crafts	63	13.8%
Hydrographic Survey Vessels	13	2.9%
Lighthouse Tenders	10	2.2%
Training Boats	3	0.7%
Total number of vessels and craft	455	100%

Source: Japan Coast Guard. (2015). *JCG - Keeping the oceans safe and enjoyable for future generations!*. Retrieved from http://www.kaiho.mlit.go.jp/e/index_e.htm

Moreover, the other types of ships are responsible for salvage, maritime environmental protection and so on. Thus, the classification of JCG's vessels is completely different from USCG. The rest of ships, besides Patrol Vessels, have been divided into survey vessels and rescue crafts. As of April 1, 2015, the JCG controls 63 Special Guard and Rescue Crafts and 13 Hydrographic Survey Vessels.

As the above paragraphs present, the number of Special Guard and Rescue Craft (63) is less than the total quantity of areoplanes (74). Thus, air force plays an important role in Japan's search and rescue operations. Although other types of ships can assist in searching and rescuing, the actual rescue activities still are completed by the Rescue Crafts because they are equipped with professional equipment. Therefore, the power of professional rescue ships and airplanes cannot be ignored. When other situations kept same, vehicles that usually are selected in rescue operation will become the main force in rescue activities. Vehicles that have larger amount of will

stand a higher chance to be used. In that case, JCG flights will be more reliable than rescue craft in Search and Rescue operations.

2.4 China Rescue and Salvage

China Rescue and Salvage (CRS) is the only professional maritime salvage and rescue force that has been admitted by the Chinese Government. CRS is mainly in charge of the protection of life, property and environment on the sea area under China's jurisdiction. Thus, CRS will send professional force to the area where accidents happen, if there are marine accidents which require life-saving, fire-fighting, spill clean-up services and so on. At the same time, CRS is responsible for some extra tasks, including safeguarding marine transport and exploitation of marine resources. More importantly, CRS will undertake some missions that fulfill the state obligations on behalf of the People's Republic of China as stipulated by international conventions and bilateral maritime agreements (CRS, 2016).

CRS has been operating for almost 65 years, since it was firstly founded by August, 1951. In the past 65 years, CRS had been reformed and expanded under the guidance of Ministry of Transport. The primary purpose of CRS is to catch up with the international level of rescue and salvage and to create development programme in accordance with Chinese economic development. CRS has created a new organizational structure that divides its liabilities into three departments, including Rescue Bureau, Salvage Bureau, Flying Rescue Service. The organizational structure is basically made up of air rescue force, ship rescue force and property salvage force, so the three forces can cover almost all kinds of maritime accidents. Meanwhile, the three forces represent three different abilities such as submarine diving and salvage capacities, helicopter rescue power and quick response

capabilities on water.

CRS is composed of headquarters and branch. With its headquarters in Beijing, the CRS has divided the branch into four departments, including Rescue Bureau, Salvage Bureau, Flying Rescue Service and Affiliated Companies. Each department has arranged its branches through maritime district. For example, Nanhai No.1 Flying service team that belongs to Flying Rescue Service is responsible for the South Sea of China. Beihai Rescue Bureau, belonging to Rescue Bureau, is in charge of North Sea of China. As the above paragraph mentioned, Salvage Bureau only takes charge of property salvage functions. Thus, Rescue Bureau and Flying Rescue Service are the main force for search and rescue operations. Although each Rescue Bureau branch has 6 bases at least (the total number of the base in Rescue Bureau is 21) that can cover almost every main ports in China, the Flying Rescue Service owns merely eight bases which are hardly covered within the Territory Sea and EEZ of China. The distribution of CRS' headquarters and bases is shown in Figure 5.

Figure 5 Distribution of CRS' headquarters and bases

2.4.1 CRS planes and facilities

There are 20 helicopters under CRS's control, including 4 large size helicopters (Super Puma 225), and 16 middle size helicopters (Sikorsky 76D or 76 C+). Although their longest range is only 472 nm, it is easy for helicopters to get close to ships in distress because helicopters can hover on the top of the ship. Helicopters are the main force to rescue people in danger.

There are two types of maritime rescue helicopters in the Flying Service team. One is called S-76C+, which is developed by Sikorsky Aircraft Corporation. S-76C is created to work in marine environment, so it is responsible for maritime rescue,

offshore oil exploration and medical operation. Most of CRS' flights are S-76C+ -the best rescue helicopter in the world. The aircraft is famous for its flying capability, security and economy. Its gross weight is 5,307 kg, so the airplane can carry 13 people once. Moreover, S-76+ is mainly supported for middle range search and rescue operations for its 411 nm maximum range. At the same time, the reason to consider that S-76C+ is one of the best rescue helicopter is for its modifying ability and automatic pilot. It is easy for the aeroplane to be equipped with extra facilities, including rescue hoist, infrared imager, rescue basket, Doppler weather radar and so on. Furthermore, the automatic pilot system- SPZ-7600 can help pilots hovering flights automatically.

Figure 6- CRS' S-76D

Another flight is called EC225 which is modified from Super Puma AS332. The updated version consists of composite, so it enhanced the crashworthiness of EC225. Most importantly, EC225 is equipped with two turbine engines which increase the gross weight to 11,000 kg and the maximum speed to 324 km/h. Thus, this type of helicopter undertakes more important role in rescue operations, because it can carry more people and equipment and hover over the sea at a longer time.

Figure 7- CRS' EC225

2.4.2 CRS vessels and facilities

CRS has 199 vessels of various kinds, and only 38% of the total vessels are used for rescue operation. The rest of ships belong to Salvage Bureau. Compared with 20 helicopters, vessels are still the main rescue tool in China. What's more, there are much more water bases than air stations, so it is easy for vessels to find supply. To synthesize each situation, helicopters cannot replace the role of rescue ships in China.

Although water force is stronger than air force in China, flight will be the future trend in rescue operation. Firstly, China owns 18,000 km coastal line and 3 million km2 territorial sea area. To such a huge area, it will take a longer time if the rescue operation highly relies on vessels. Compared with helicopters, the speed of vessels is pretty much slow, but the truth is that the time is very limited in rescue operation.

Secondly, the cost of air station is lower than that of ship base. Basically, it is much easier for air station to find an appropriate location for depth of port is an important factor to be considered by Ship base. Also, ship requires more people to control and repair. Therefore, the cost of air station is much cheaper than water base. Finally, the cost of helicopter is much cheaper than ship's.

2.5 Conclusion Remark

Among all the three countries, helicopters are the main force for rescue operation because of its cost and convenience. Although three countries own a large amount of ships, the majority of them are used for other purposes such as surveillance, salvage and so on. Furthermore, the rescue team of three countries has different organizational structure due to states' obligation, but none of them forget to add flights under the structure. In other words, air rescue is an indispensable force in rescue operation.

CHAPTER 3

The Advantage of helicopters in maritime rescue

3.1 Introductory Remark

Shipping has been considered as a high risk occupation since ancient times. However, with the development of international trade, shipping, as a main force on seaborne trade, has been enlarged for several times. According to the text book-Maritime Economics (Shuo Ma, 2015), the maritime traffic had been increase from 20 million tons in 1840 to 9,548 million tons in 2013. Simultaneously, maritime accident which is symbiotic relationship with shipping has kept increasing from the past to nowadays. To protect human life, maritime rescue becomes a primary task for every maritime state. Moreover, limited time is the main concern for rescue operation. As a matter of fact, people cannot survive on the sea for a long time. Therefore, rescue organization which can send response team to accident spot faster will save more lives. Although there are 21 rescue vessel bases in Chia, it usually takes several hours to leave the harbor because it includes preparing time and time to arrive at accident spot. If the weather is worse, the arriving time will increase. In that case, person in distress will face the most dangerous situation. Thus, advanced search and rescue equipment will be the key factor, for those equipment can reduce preparing and searching time. More and

more organizations choose helicopters to be their main rescue force. In this chapter, it will discuss the efficacy of helicopters in maritime rescue.

3.2 The speed of helicopter is fast

As the table 2 shows, the maximum cruising speed of helicopter is between 142 kt and 155 kt. In the meantime, the vessels' average cruising speed is 20 kt. The contrast of cruising speed between helicopter and vessel shows that the speed of helicopter is 7 times faster than the speed of ship. Obviously, faster speed vehicle will be much helpful for search and rescue operation. There are two main reasons for the preference to faster speed vehicle.

Table-2 Helicopters' attributes

Type of helicopter	Maximum cruising speed	Maximum Range
S-76D	155 kt	472 nm
H225	142 kt	613 nm

Source: Sikorsky A Lockheed Martin Company. (n.d.). *S-76D™ Helicopter*. Retrieved from http://www.sikorsky.com/Pages/Products/Commercial/S76/S76D.aspx

Airbus Helicopters. (2016). *Civil Range*. Retrieved from http://www.airbushelicopters.com/website/en/ref/H225_40.html

On the one hand, human being lost their temperature 25 times faster in water than in air, so people are easy to feel cold in water. In the worst situation, people will lose their consciousness. According to the research (Wang Juan, 2015) and Table 3, a healthy adult will lose his or her consciousness in 15℃ water after 3.5 hours. If the water temperature drops to 10℃, people will hardly survive 1.5 hours. Also, people will not survive in the water in no longer than 100 minutes if the water temperature does not exceed 0℃. Accordingly, rescue organizations which spend less time in preparing and searching will save more lives in distress. There are a lot of fishers

and ships operating in the South Sea of China. CMSRC has received a lot of emergency rescue calls every day. It usually takes 9 hours for rescue ships to arrive at accident spot, because the distance between Sanya ship base and Yongxing Island is about 180 nm. However, it only takes helicopter 1.5 hours on road. Time is life, at this moment has been expressed cruelly.

Table 3-Guide to survival time for persons without special protective clothing in water of various temperatures

Temperature (℃)	Expected time of survival
Less than 2	Less than 0.75 hour
2 to 4	Less than 1.5 hours
4 to 10	Less than 3 hours
10 to 15	Less than 6 hours
15 to 20	Less than 12 hours
Over 20	Indefinite (depends on fatigue)

Source: IMO, & ICAO. (1998). *International Aeronautical and Maritime Search and Rescue Manual*. United Kingdom, UK:Ashford Press

On the other hand, it is almost impossible to predict the change of ocean current based on present technology. There are many examples to demonstrate that ocean current carries people or big objects to unpredictable locations. For instance, the search for MH370 had been suspended recently because ocean current had already carried it to unknown place in the Indian Ocean. China, Malaysia and Australia had spent a lot of time and resource in searching MH370, but MH370 was still unfound. Compared with such big object, people are much smaller and hardly to find on the ocean. Thus, it will increase the possibility of searching for people in distress because helicopter can arrive at accident spot faster than ship. Furthermore, the range of search area can be precisely calculated when helicopter arrives in time. In

other words, helicopter assists in reducing the difficulty of search and rescue operation.

3.3 Wide Vision

Normally, people who stay at a higher position can see farer. The theory is the same for the efficacy of helicopter. Helicopter which flies in the air has a wider view than ship. Rescue helicopter is required to patrol at the altitude between 60m and 150m high. The altitude is suitable for lifeguards or crews to search for people in the water. Meanwhile, the altitude of helicopter overcomes the limit of horizontal view on ship. Due to those reasons, helicopter is more suitable for finding vessels or rafts. In addition, helicopter is more flexible and compatible. It is easy for helicopter to turn around because of its agility, so helicopter has a larger search radius. Unlike ship, it needs a large angle to turn around. The designer of helicopter has already reserved places to equip new tools such as navigation precision equipment (sensors, inertia reference system), infrared search equipment, advanced automatic control system and so on. According to the Figure 8 and 9, it is worth mentioning that infrared search equipment can seek people or ships with 360 °view and has 3,000 m detected range. Those facilities assist crew members in locating and finding target precisely, so it can promote search activities efficiently and reduce the cost.

Figure 8 & 9 – Advanced searching equipment

Source: Airbus Helicopters. (2016). *H225*. Retrieved from

http://www.airbushelicopters.com/website/en/ref/H225_40.html

3.4 All-weather operation

A majority of ship will stay at port if the weather is terrible. The main reason of reaching port is to shelter wind and waves, because strong wind and waves can increase the probability of collision and capsizal. It is very dangerous for rescue vessel to get close to ship in distress because of the same reason mentioned above. Rescue vessel has to keep a safe distance away from the ship in distress, but the distance will increase the difficulty of rescue activity. However, helicopter can overcome the difficulty, for it is less influenced by wind and waves than ship. There is no doubt that waves barely affect helicopter.

Simultaneously, some types of helicopters own high resistance to wind. As Airbus Helicopter report (2016) shows that, EC225 (H225) with a rotor de-icing system can fly in all-weather conditions. Its Autopilot control system facilitates pilots to remain stable flying in the strong wind. What's more, the Figure 10 reveals that helicopter can keep less than 1 m hovering accuracy by fully automatic transition.

Figure 10-Automatic Transition

Source: Airbus Helicopters. (2016). *H225*. Retrieved from http://www.airbushelicopters.com/website/en/ref/H225_40.html

Thus, using helicopter can get rid of the high probability of collision in extreme

weather conditions and can increase the possibility of successful rescue operation. For example, a cargo ship flooded in 33 nm away from the Southwest of Zhuhai, because the weather of Pearl River estuary which was affected by typhoon-Nesat became terrible in September, 2011. It is almost impossible for rescue vessel to get close to the sinking ship because of the extreme weather condition (strong gale). Nanhai No.1 Flying service team received the emergency call and sent EC225 aircrew to rescue people immediately. Although the wind and waves were strong, they finally saved all 12 people in the last minute of ship sank. It is clear to see that EC225 is less affected by weather conditions. EC225 can hover over the ship no matter how ship is influenced by the bad weather. Meanwhile, people in distress will be encouraged when they see surviving hope.

3.5 Vertical Take-off and Landing (VTOL)

According to the research (Stanton, Plant, Roberts, Harvey & Thomas, 2015), "Helicopters tend to perform take-off and landing manoeuvres that are unlike fixed wing aircraft, generally being steep and with greatly reduced landing distances at both managed and unmanaged landing sites". Helicopter is less affected by terrain and sea conditions, so it is easy for helicopter to search islands in sea. Moreover, the requirement of helicopter's landing area is few. If people are taken to island by waves, helicopter can easily find a landing location to rescue all people. Unlike ship, it must drop anchor at a certain depth of water to avoid stranding. In comparison with ship, helicopter is a more efficient tool to rescue people.

3.6 Joint air-sea rescue operation

The other efficacy of helicopter is to promote the efficiency of rescuing power. Although the above paragraph has shown the disadvantages of ship on rescue operation, vessel is still a useful tool to support search and rescue. The strength of

vessel includes high endurance and large capacity. Helicopter can integrate its superiority with the strength of vessel to improve the total efficiency of search and rescue activity. The method to improve rescue efficiency will be described as the following:

Firstly, helicopter will be scoutplane if there are a lot of targets in distress. Vessels will receive the information sent by the scoutplane, then move to accident spot. The rest of rescue operation will be completed by ship because helicopter has a certain holding capacity. It can save the time that is wasted in searching. Meanwhile, helicopter can drop lifesaving equipment and necessary supply to those people. Secondly, helicopter can transfer a portion of people in distress to nearby ship or island while sending the location to rescue vessel, if there are many people in sea. The cost of round-trip time will be saved by reducing the transferring distance, so more people will be survived. Thirdly, helicopter can help in connecting line between rescue ship and vessel in distress when weather is terrible, since there is a high probability of collision. To use helicopter as a third party is a safe way to connect two ships. Fourthly, if rescue vessels need to transfer people and materials to ships in distress in an extreme weather, helicopter is trustworthy to be relied on in the mission because of its hovering capability. Thus, helicopter is not only an efficient rescue tool, but also has an associated ability to improve the success rate of rescue.

3.7 Conclusion Remark

In this chapter, it has discussed the efficacy of helicopter in maritime rescue. It demonstrates that helicopter has positive impact on rescue operation and the air force is necessary to rescue activity. Using helicopter as the main rescue tool will improve the probability of saving survivor because helicopter has unique efficacy on

maritime rescue, characterizing by its fast speed, wide vision, the ability of all-weather operations and cooperative capability.

CHAPTER 4

The optimized diorama of maritime rescue

4.1 Introductory Remark

The joint air-sea rescue operation is a collaborative activity that combines both air forces (aircraft) and water forces (ships). The joint operation is the most effective way to find people or ships in distress because it synthesizes advantages of both helicopter and ship. With the technology of access to information on maritime search power matures, planners have been able to find the dynamic information with searching area and available surrounding searching power such as its position, speed and direction. In other words, the ability to collect search information gets promoted. When there are many available search forces, the most practical problems that maritime search and rescue operation is facing frequently include how to choose aircrafts and ships among different models, how to make them work together to implement fast and efficient search operation with a wide coverage in the shortest time. In this chapter, optimized mathematical model is set up to solve those practical problems. By setting up the mathematical model, there will be some optimal solutions. In contrast with each solution, this chapter finally will get a project that maximizes the utilization of sea and air forces. Then, it will show that vehicle which completes more tasks is the most efficient in the rescue operation.

4.2 Model Establishing

（1） To assume the searching sea area is S(n mile^2)

（2） To assume there are the quantity of M rescue vessels and N areoplanes in searching sea area；

（3） To assume the distance between every rescue ship and initial searing sea is D_i^v(n mile)， $i = 1, \cdots, M$; and the distance between every rescue flight and the initial location of accident spot is D_j^a(n mile),$j = 1, \cdots, N$;

（4） To assume the maximum cruising speed of each rescue vessel and aircraft is $\hat{V}_i^v$ （kn）,$i = 1, \cdots, M$ and $\hat{V}_j^a$(kn) ,$j = 1, \cdots, N$ respectively;

（5） To assume the search and rescue capability of each ship and plane is A_i^v(n mile^2/h),$i = 1, \cdots, M$ and A_j^a(n mile^2/h), $j = 1, \cdots, N$ respectively;

（6） To assume the maximum endurance of each flight is T_j^L(h), $j - 1, \cdots, N$;

（7） To assume the frequency of each flight that departs air station in the whole search and rescue operation is $L_j, j = 1, \cdots, N$;

（8） To assume the maximum number of rescue ship can accommodate in the sea area is Q^a $(1 \ll Q^a \ll N)$;

（9） To assume the total cost of time for the operation is T(h).

Then:

1) When No. i ship is sailing to searching sea area at full speed, the duration of voyage is $\hat{T}_i^v = D_i^v / \hat{V}_i^v$;

2) When No. i ship is seeking in the sea area, the duration of its operation is $\bar{T}_i^v = T - \hat{T}_i^v$;

3) When No. j plane is flying at full speed, the required time of round trip is $\hat{T}_j^a = 2D_j^a / \hat{V}_j^a$;

4) When No. j plane is searching the sea area, the duration of its operation is $\overleftrightarrow{T}_j^a = T_j^L - \hat{T}_j^a$;

5) The frequency of departure by No. j plane is $\mathrm{L}_J = T / T_j^L$.

In order to spend as less time as possible in searching the accident sea area, it needs to analyze the composition of the water force and air force during the entire time of search operation. To assume the begging time is t_s , and ending time is t_e, so the time of entire search operation is $\mathrm{T} = \mathrm{t}_e - t_s$.

Simultaneously, this article will suppose that the round-trip time is equal and assume that the time spent in refueling is null because it can simplify the calculation. The total time ($\bar{T}_j^a$) of plane a_j which is spent in the search and rescue during the entire search operation (T) is equal to the sum of every time searching duration ($\overleftrightarrow{T}_j^a$).

Therefore, the formula is $\bar{T}_j^a = L_j \overleftrightarrow{T}_j^a$. In the meanwhile, the every time searching duration ($\overleftrightarrow{T}_j^a$) equals to that the maximum endurance time T_j^L minus the round-trip time $\hat{T}_j^a$, so it should be $\bar{T}_j^a = \mathrm{L}_j\left(T_j^L - \hat{T}_j^a\right) = \mathrm{L}_j\left(T_j^L - 2D_j^a/\hat{V}_j^a\right)$

According to above paragraphs, the formula to cover the whole searching sea area is equivalent to:

$$\sum_{i=1}^{M} \bar{T}_i^v A_i^v x_i + \sum_{j=1}^{N} \bar{T}_j^a A_j^a y_j = S$$

Also,

$$\sum_{i=1}^{M} \left(T - \hat{T}_i^v\right) A_i^v x_i + \sum_{j=1}^{N} \left(T - \frac{T}{T_j^L}\hat{T}_j^a\right) A_j^a y_j = S$$

To solve T, the formula will become:

$$\begin{cases} global\min T = \dfrac{\sum_{i=1}^{M} \hat{T}_i^v A_i^v x_i + S}{\sum_{i=1}^{M} A_i^v x_i + \sum_{j=1}^{N} \left(1 - \frac{\hat{T}_j^a}{T_j^L}\hat{T}_j^a\right) A_j^a y_j} \\ s.t. \quad \sum_{i=1}^{M} x_i = Q^v, \ 1 \ll Q^v \ll M \\ \sum_{j=1}^{N} y_i = Q^a, \ 1 \ll Q^a \ll M \end{cases}$$

4.3 Data analyze

Proposing the following assumptions: the searching sea area is 2,000 (n mile)2, and the area contains 12 ships and 4 aeroplanes. 11 ships are searching the surrounding

area, but the rest of ship is seeking the accident area. Table 4 presents the ship's initial distance with the accident area, maximum speed and the capability of search and rescue. Also, Table 5 reveals some related information with flight. For this calculation, all ships and flights data are collected from practical figures. For example, all flights' attributes come from the practical helicopters such as S-76D and H225.

Table 4-Ships' basic attributes

Ship No.	Initial Distance D_i^v(n mile)	Maximum speed $\hat{V}_i$ (kn)	Searching ability A_i (n mile^2/h)
1	0	7	8
2	24	13	15
3	25	30	49
4	27	15	20
5	28	32	55
6	65	15	19
7	72	20	41
8	78	18	25
9	85	16	21
10	92	22	60
11	94	23	62
12	97	21	58

Table 5- Planes' basic attributes

Flight No.	Initial distance D_i^a (n mile)	Maximum speed $\hat{V}_j^a$ (kn)	Maximum endurance T_j^L (h)	Searching ability A_i (n mile^2/h)
1	20	155	4.26	180
2	33	175	5.66	220
3	490	175	5.66	220
4	245	155	4.26	180

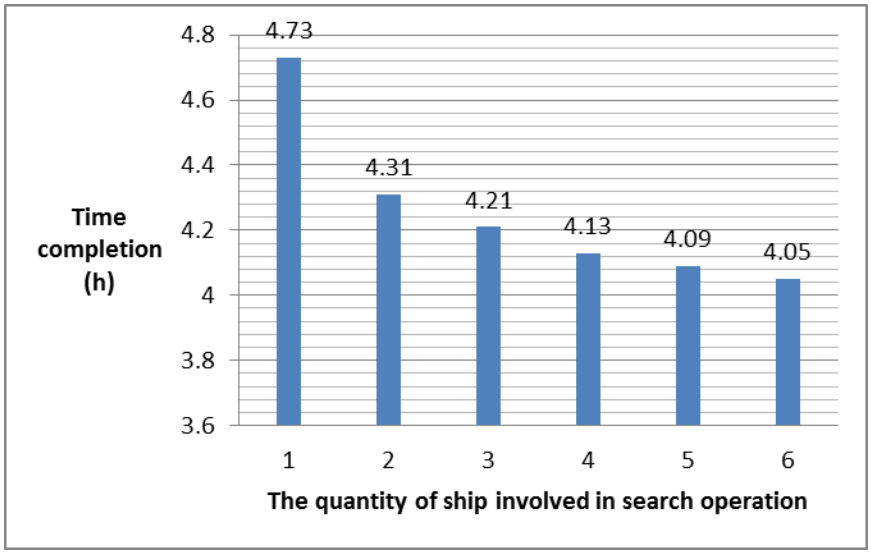
4.4 Calculating Result

By using the above data to calculate, there are 37 kinds of feasible and optimal rescue schemes. According to these schemes, with the increasing number of forces involved in the search operations, the time required to complete the searching coverage will be gradually reduced. Moreover, the extent of decrease is shrinking. The reason for this situation is that the remaining unexplored area accounts for the proportion of the total search area declining as the search operation proceeds. The contribution, brought by newly added searching forces, becomes smaller and smaller to the entire operation. Thus, it is impossible to calculate the completion of time for entire search area if there are two variables such as the number of ships and flights involved in search and rescue operation are uncertain. To analyze the completion of time for entire accident area by controlling different variables, it assists decision makers in finding the most efficient option with the least search and rescue forces. The analysis will be described as following:

Firstly, it is to analyze the change of time that completes the search coverage based on different number of ships involved, when the quantity of aircraft is constant. Assuming that there are 3 planes involved in the rescue operation, the question will

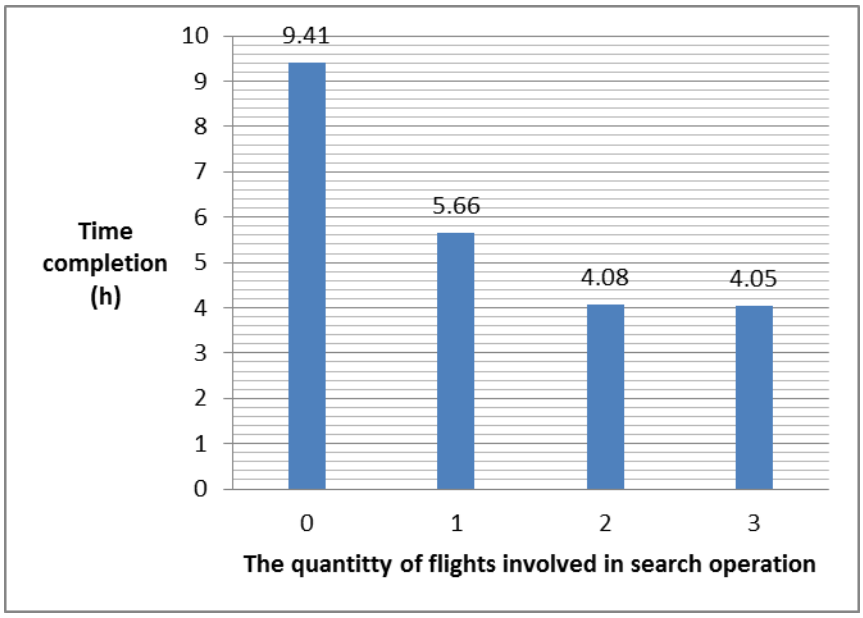
be how many number of ships involved in the operation can bring the optimized result. Consequently, the model has provided schemes with 6 kinds of ships arrangement that can facilitate the reduction of time completion on the operation. The time spent on each arrangement is revealed in the Table 6.

Table 6- Time required among different schemes of ships



Secondly, it is to analyse the change of time to complete the entire search operation by using different flights when the vessel quantitative constraint is the same. In fact, when the number of attending search and rescue ship is 6, the model gives four schemes with using different quantitative planes. It basically requires from 0 to total of 3 flights to join the search operation. The change of time completion by flights is shown in Table 7. According to Table 7, the time with one flight involved in the operation is less than the time of none flight option by 3.75 hours, so the time completion of entire search and rescue operation will be largely reduced by using flights.

Table 7- Time required among different schemes with flights



However, the extent of decrease is gradually declined with the increasing number of flights used in the operation. Furthermore, the time with one flight option takes 1.58 hours more than the time of the two flights' option. The time completion by using 3 flights is only 2 minutes less than the time of the two flights' option. What's more, the workload by No.3 planes has only occupied 1% of total search coverage from the table 10. Table 8, Table 9 and Table 10 show the workload by different quantitative flights. Meanwhile, tit needs to be considered into the model that the accident usually happens in the extreme weather conditions, so flights are also facing the danger. Therefore, it is reasonable for the model to reduce the number of flights involved in the operation and prolong an appropriate amount of search time under the comprehensive consideration of the relationship among three factors, including weather and sea conditions, the aircraft's ability to withstand harsh environment and the contribution to entire search operation by newly added aircraft. From the calculation, the time with 2 flights option has just 2 minutes more than the time with 3 flights' option, so it should choose the 2 flights' option in the search and rescue operation if the search time is not that urgent.

Table 8- One Flight workload

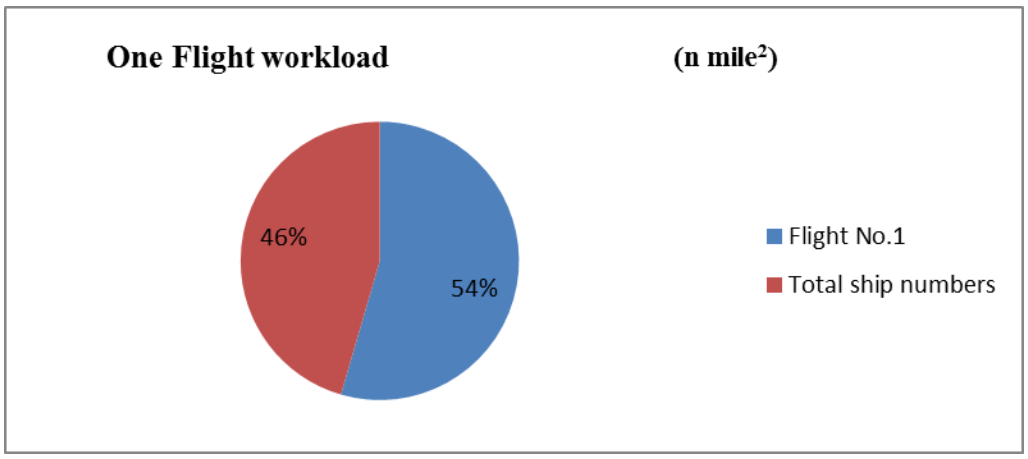


Table 9- Two flight's workload

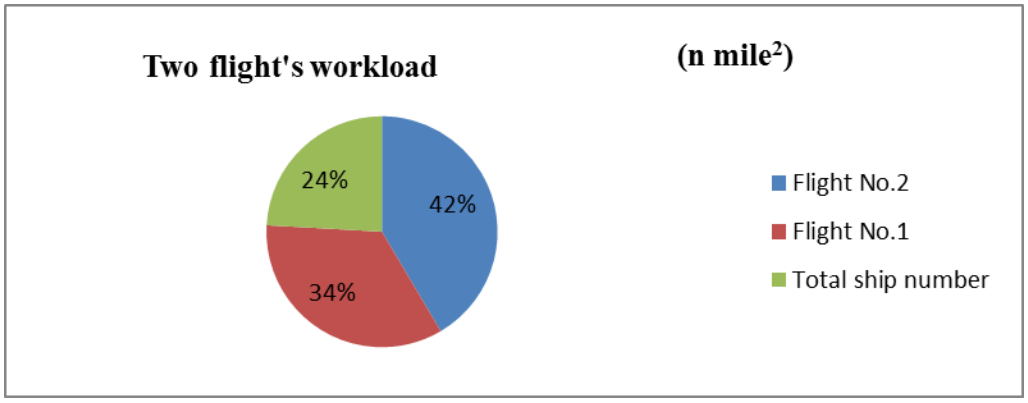
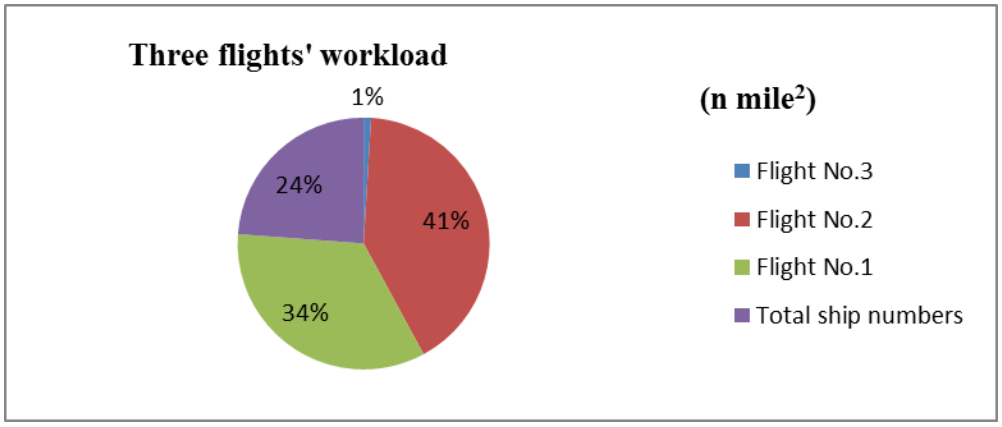


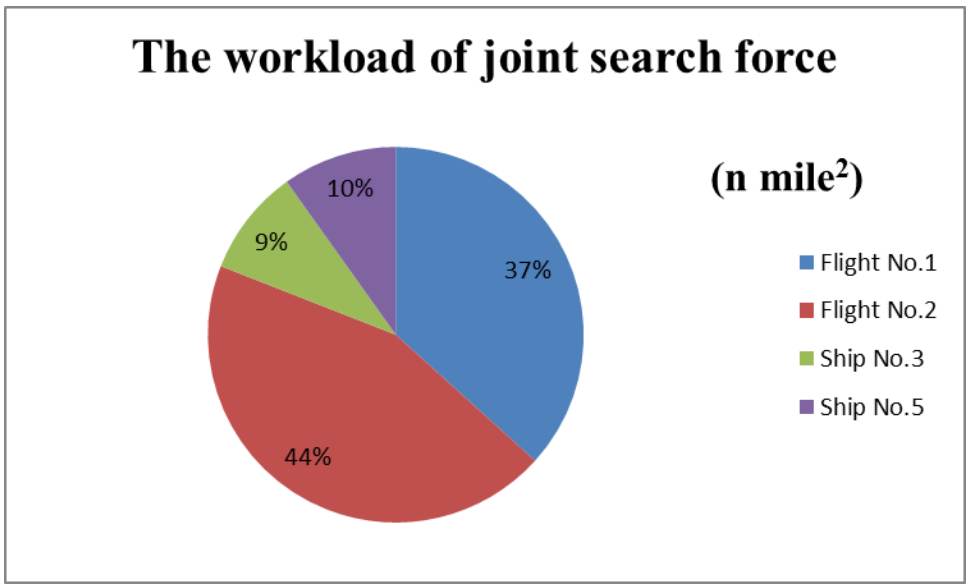
Table 10- Three flights' workload



By comparing the cost of time (from Table 6 and 7) and coverage workload for each flight scheme (from Table 8 to 10), the final optimal scheme is to choose a combination among flight No. 1 and No. 2 as well as ship No.3 and No.5. The joint

air and sea search force will take 4.35 hours in searching the whole coverage area. The optimal scheme's time is only 18 minutes more than the shortest time scheme which cost 4.05 hours with 3 flights and 6 vessels. Table 11 shows the result of optimal solution to search and rescue operation.

Table 11- The workload of joint search force



4.5 Conclusion Remarks

The purpose of the model is to reduce the cost of searching time-T which covers the whole sea area at most by selecting the best search and rescue ship and aircraft and making them work together. At meantime, the comparison between rescue ship and aircraft can verify their effectiveness and indispensability. In comparison with Table 7 to 10, the figure proves that helicopter has a positive impact on maritime search and rescue operation. Moreover, the model demonstrates that helicopters are more effective in the rescue operation, since the workload of helicopter is more than ship's in most of the tables.

CHAPTER 5

An overview of improvements in rescue helicopter

5.1 Introductory Remark

The air and sea joint force is the trend of development in search and rescue operation. The rescue helicopter will play more and more important role because it has the quick response ability, the ability with high resistance to extreme weather conditions and wide searching area. Its characteristics cannot be replaced by rescue vessels. This chapter is going to discuss the limit of helicopter in rescue operation and the improvement to rescue helicopter.

5.2 The limits of rescue helicopter

Although rescue helicopter improves the efficiency of maritime rescue as above proved, rescue helicopter has its limits, including:

1. The helicopter must hover at a certain altitude when it is completing rescue operation. The reason to require the certain height is that the rotor wing of helicopter will produce a strong impulse downwards to push helicopter upward. If the helicopter gets as close as possible to the ground, it will create a ground effect because the downward airstream interacts with ground. The ground effect will

overthrow life raft.

2. The limited interspace of helicopter is also a difficulty for rescue operation. For example the maximum crew capacity for a helicopter is 19 beside the 2 pilots. Since the catastrophe accident has keep increasing in recent years, the limited seats or space for rescue helicopter is a new problem for the maritime search and rescue.

3. The successful rescue operation for helicopter is based on many factors, including the visibility of maritime accident area, the degree of wind-force and ship rocking degree. According to IAMSAR MANUAL (1998), the searching height of aircraft should be 300 m to 600 m during daylight or 600 m to 900 m at night. Thus, the basic requirement for helicopter to rescue contains 300 m vertical visibility, 1 mile horizontal visibility and 50 kn wind speed. Under such circumstance, helicopter can guarantee the possibility of safe and successful maritime rescue.

5.3 Improvements in rescue helicopter

To overcome the above limits, the joint search and rescue system is important for future development of rescue operation. The improvements for rescue helicopter are presented in the following:

1. It is very important for developing rescue team to strengthen management. To learn the advanced management mode of developed countries, developing countries can save the time and resources. For instance, China Flying Service team has learnt a lot of experience from Hong Kong Government Flying Service. They have direct partnership, so HKGFS has sent a lot of experienced staff to give lectures.

2. Rescue helicopter should improve advanced personnel training of different levels

because the rescue helicopter crews usually are facing extreme conditions. The lack of experienced helicopter flight instructor is a problem for every country. However, USCG has dealt with the problem successful. USCG requires the experienced pilots to leave the rescue field temporarily and to become an instructor in the pilot academy. Thus, experienced instructors can share their thoughts and experience while they do not leave the practical field for too long.

3. To explore the establishment of search and rescue integration mechanisms, so that resources can be fully utilized. As the above model proves, the joint search and rescue system can optimize the cost of time and resource. Moreover, advanced searching and rescue equipment not only increase the efficiency, but also improves the safety of helicopter. As the research (Stanton, Plant, Roberts, Harvey & Thomas, 2015) shows, the main function of HUD system is to present flying related figure, including altitude, speed of wind and so on, directly on the windshield display. The new technology digitalizes the environment, so that it can help pilots make decision more easily and correctly.

5.4 Conclusion Remarks

To sum up, the joint research and rescue system is the trend for the future rescue operation and the developing countries which want to catch up with developed countries should pay more attention to the recent change of maritime rescue. Also, this chapter provides some suggestions on improvements for rescue helicopter. Those improvements not only benefit maritime search and rescue, but also promote the safety and management of helicopter organization or company.

CHAPTER 6

Summary and Conclusions

With the development of world economy, international trade is gradual increase, because capital is always looking for new profits. As long as the international exchange of good keeps bringing benefits to stakeholders, the shipping industry will remain flourishing. However, the problem brought by high interest is that stakeholders will ignore the potential risk which is cumulating until the accident happens.

To prevent accidents from happening, national search and rescue team has been built. Time is life for both survivors and rescuers, so the question of how to improve the efficiency of maritime search and rescue becomes significant. Furthermore, marine accidents often occur in extreme weather conditions. It needs a flexible vehicle to deal with all urgent situations. On the basis of the research (BHA, 2016), helicopters can change its role when the operational environment has been varied. It shows that helicopter is a flexible vehicle that accommodate new environment quickly. Therefore, helicopters are introduced into maritime search and rescue operation.

Moreover, United State and Japan which have a wide EEZ have already adopted

helicopters into their national rescue system. Those two countries have found out helicopters' properties are suitable for the rescue operation. Simultaneously, China has set up a public institute for specializing in using helicopters. The situation that all three countries have helicopters in their national rescue team proves the usefulness of helicopters. The common area of the three countries for their national rescue team is to make a quick response team for search and rescue. The efficacy of helicopters in maritime rescue is to improve the survival ratio and to have a positive impact on the result of emergency rescue. The character of helicopter is the main reason to create those efficacies for marine rescue because maritime rescue needs its speed, visibility, all-weather and joint capabilities.

Although the practical field has demonstrated the efficiency of helicopter, it is better to have a theoretical support. This research paper uses a mathematical model to calculate an optimal group with the largest workload that spends the fewest time. The model not only verifies that the search and rescue joint force will be the future trend, but also shows that helicopters make more contribution than other vehicles in rescue operation. Some recommendations for helicopters are provided to improve their management and to facilitate the process of future joint search and rescue.

REFERENCES

Airbus Helicopters. (2016). *Civil Range*. Retrieved from http://www.airbushelicopters.com/website/en/ref/H225_40.html

Airbus Helicopters. (2016). *H225*. Retrieved from http://www.airbushelicopters.com/website/en/ref/H225_40.html

British Helicopter Association. (2016). Retrieved from http://www.britishhelicopterassociation.org/?q=content/future-role-helicopters-public-transport

Chen, J., & Yang, Y. (2008). Brief discussion on rescue equipment in China and the United States maritime search and rescue system. *Manager Journal, 15*, p.231-232

China Rescue and Salvage of Ministry of Transport of the People's Republic of China. (2016). *CRS Today*. Retrieved from http://eng.crs.gov.cn/AboutUs_CRS/Today_About/

HH-60J [Imagine]. (2013). Retrieved from http://www.usnook.com/military/aircraft/helicopter/2013/0930/64015.html

Japan Coast Guard. (2015). *JCG - Keeping the oceans safe and enjoyable for future generations!*. Retrieved from http://www.kaiho.mlit.go.jp/e/index_e.htm

MH687 [Imagine]. (2016). Retrieved from http://www.kaiho.mlit.go.jp/soubi-yosan/soshiki/air/mh687.jpg

Sikorsky A Lockheed Martin Company. (n.d.). *S-76D™ Helicopter*. Retrieved from http://www.sikorsky.com/Pages/Products/Commercial/S76/S76D.aspx

Stanton, N., A., Plant, K., L., Roberts, A., P., & Harvey, H. (2016). Extending helicopter operations to meet future integrated transportation needs. Applied Ergonomics, 53, 364-373. doi:10.1016/j.apergo.2015.07.001

Units [imagine]. (2014). Retrieved from http://www.uscg.mil/top/units/

Wang, D., (2007). Approaches and characteristics of maritime search and rescue helicopters. *Work Safety and Supervision*, *2*, 18-20.

Wang, J., (2015). Brief analysis of characteristics and application of helicopters in maritime search and rescue. *Technology Wind*, *11,* 123-124.

Wan, Q., (2014). Analysis of flight of rescue helicopters under complex weather conditions. *Technology Wind*, *14*, 211.

Zhang, Z., & Zhang, S. (2011). U.S. maritime search and rescue system analysis. *China Emergency Rescue*, *4*, 45-48.

BIBLIOGRAPHY

IMO, & ICAO. (1998). *International Aeronautical and Maritime Search and Rescue Manual.* United Kingdom, UK: Ashford Press.

Ma, S. (2015). *Maritime Economics.* Unpublished lecture handout, World Maritime University, Malmö, Sweden.