Research and Development of Launch Vehicle Recovery Ship and Response to Ship Class Rules

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1. PURPOSE AND BACKGROUND

The Japan Aerospace Exploration Agency (JAXA) is studying a "Mainstay Launch Vehicle Development Space Transportation System" (hereinafter, "reusable launch vehicle"), which is being developed aiming at substantial cost reduction, targeting the first launch around 2030, to secure the development and success of Japan's space development missions. This report presents a brief outline of the status of study of an offshore launch vehicle recovery ship (hereinafter, recovery ship) for recovery of reusable launch vehicles in offshore waters. It should be noted that development of the reusable launch vehicle has only begun, and the specifications, launch site and other matters related to reusable launch vehicle described in the following are proposals which are under study. Likewise, the recovery ship has not been finalized, and is also still in the stage of identification of functional requirements and tradeoffs among multiple types of vessels. This paper was prepared by adding Chapter 5, "Initiatives for Risk Assessment of the Recovery Ship" to a paper contributed to the *Journal of the Japan Institute of Marine Engineering* [1].

2. POSITIONING OF JAPAN'S REUSABLE LAUNCH VEHICLE

2.1 Japan's "Roadmap for a Space Transportation System"

Space development and utilization, beginning with satellites, is now an indispensable part of the infrastructure that supports the lives of the Japanese people and socioeconomic and security activities, including weather observation, positioning, satellite communications, etc.

Securing the independence of the space transportation system, which is a means of transporting satellites into space, has become the basis of Japan's space policy as the core infrastructure for accessing outer space.

Based on a recognition of the situation and awareness of the problems in the intensifying competitive environment in the space transportation market of recent years, the Space Utilization Subcommittee of Japan's Ministry of Education, Culture, Sports, Science and Technology (MEXT) has also decided to realize an innovative future space transportation system which achieves a fundamental cost reduction through technical innovation by the early 2040s, with the aims of securing the independence of Japan's space transportation system, ensuring its international competitiveness, and encouraging industrial development, and laid out the basic concepts for establishing a phased plan and route (roadmap) for reaching that goal [2]. Based on that thinking, MEXT established a Roadmap for an Innovative Future Space Transportation System [3) 4)].

In the Roadmap, the content concerning reusable launch vehicles is summarized as follows:

- To respond to governmental missions such as security, disaster prevention, deep space exploration, etc., the national government will promote the development of a "mainstay launch vehicle development space transportation system (reusable launch vehicle)" which will achieve a substantial cost reduction (target: approximately 1/2 the cost of the H3 rocket), aiming at the first launch around 2030.
- JAXA will identify the necessary element technologies through a dialogue with private-sector companies, and will acquire the element technologies through joint government-private sector research.
- The government and JAXA will study the specifications of flight test sites and vehicle recovery measures and maintenance methods supporting reuse, assuming that private companies will also use the facilities in tests. Flight test site maintenance and operational data, etc. will also be provided to private companies, and the government will study the necessary response to portions related to institutional issues in cooperation with the organizations concerned.

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2.2 Overall Concept of Reusable Launch Vehicle in JAXA

The overall outline of the operation process in study by JAXA toward realization of a reusable launch vehicle is shown in the following A) to D) (Fig. 1).

A) The reusable launch vehicle is launched from a launch site in Japan. After the first stage separates from the second stage, it decelerates through a process of attitude reversal and inertial flight, and lands on a platform installed on a recovery ship.

B) When the first-stage rocket has landed on the recovery ship, the fuselage of the launch vehicle is fixed stably to the ship by fixing devices installed on the ship. Measures to ensure safety are taken by removing the propellant, oxidant, etc. from the tanks. Because all the tasks from landing to securing safety must be performed without human intervention, the crew will move to a support ship (described in section 2.3) which is standing by near the recovery ship and perform the recovery work by remote operation. After confirming safety, the crew will return to the recovery ship and perform work from shipboard.

C) The recovery ship, with the first-stage secured on board, sails to the quay of a land-based inspection and maintenance facility. After the ship reaches the quay, the first-stage rocket is unloaded by a crane.

D) The first-stage rocket is transferred to the inspection and maintenance site, and the maintenance necessary for reuse is performed. When maintenance has been completed, the first-stage rocket is moved to the launch site, and the launch operation in the above A) is carried out. Thereafter, reuse of the launch vehicle is accomplished by repeating steps A) to D).

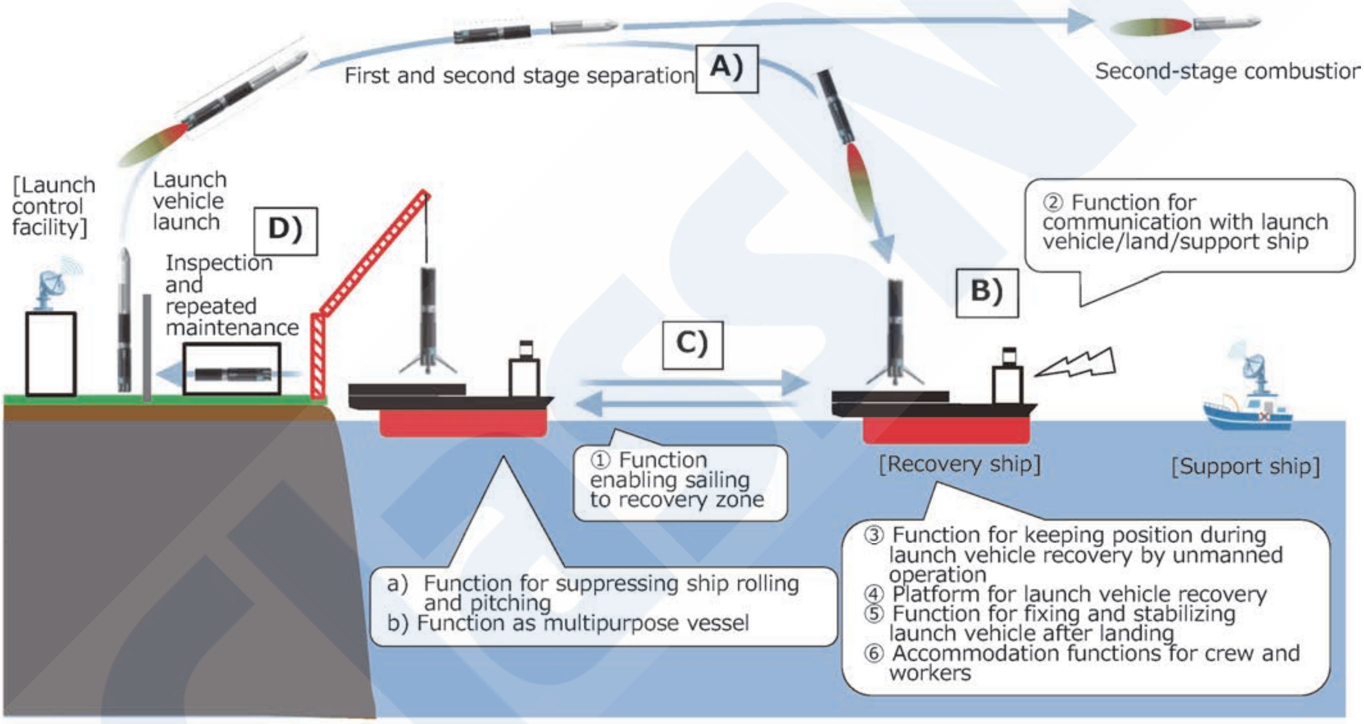

Fig. 1 Offshore recovery process by recovery ship (draft)

2.3 Candidate Recovery Zones

Locations for the reusable launch vehicle launch complex are currently under study. Although there are several candidates, the following are the results of a study assuming JAXA's Tanegashima Space Center is used. Since the Tanegashima Space Center already has equipment and infrastructure for use with the current mainstay launch vehicle, it is expected to be possible to reduce the cost of refitting facilities for use with the reusable launch vehicle by reusing the existing facilities. Moreover, it is also necessary to select the launch vehicle recovery zones considering the safety of Japan and neighboring countries. Assuming hypothetically that geostationary or earth exploration satellites are launched from the Tanegashima Space Center, the probable launch vehicle recovery areas are the waters east to southeast to south of Japan (Fig. 2). In case of earth-orbiting satellites, the candidate area is the waters southwest of Japan.

Considering the safety of the crew in the unlikely event of an explosion or fire, unmanned operation is required in launch vehicle recovery. Therefore, JAXA is studying a proposal to operate by a two-ship system consisting of a recovery ship and a support ship. As the division of roles, it is assumed that the recovery ship will be responsible for recovering the launch vehicle, ensuring safety, and transporting the launch vehicle. The support ship will be used for evacuation of the crew and remote operation of the recovery ship during launch vehicle recovery, and for tracking and control of the launch vehicle.

3. PREVIOUS EXAMPLE OF RECOVERY SHIP AND ISSUES SPECIFIC TO JAPAN

3.1 Previous Example (SpaceX)

The efforts of the American company SpaceX may be mentioned as an example of reusable launch vehicles and recovery ships [6]. The company conducts offshore recovery missions using the Falcon 9 rocket, which is equipped with 9 Merlin engines (Fig. 3), and as of April 2024, it had conducted a series of 271 launches, of which 267 missions were successful (success rate: 98.5%). Offshore recovery is performed by using a ship called an Autonomous Spaceport Drone Ship (ASDS), which is an improved barge that is capable of autonomous navigation. To date, SpaceX has constructed and is using four of these drone ships (Fig. 4). Since it is generally difficult for barges to put out to sea on long voyages due to their low freeboard height and international rules governing the autonomous operation of ships have not yet been established, it is thought that these vessels will operate within a range where special approval can be obtained from the United States government. Launch vehicle recovery is performed by unmanned operation, and control during recovery is performed by a support ship anchored nearby [7] (Fig. 5). Although the waters where launch vehicles are recovered differ depending on the mission, launch vehicle recovery is performed approximately 300 to 1 200 km off the coast of Florida.

3.2 Items to Be Considered in Japanese Recovery Ship

The situations of the United States (SpaceX) and Japan were compared, and the items that require special consideration are shown below.

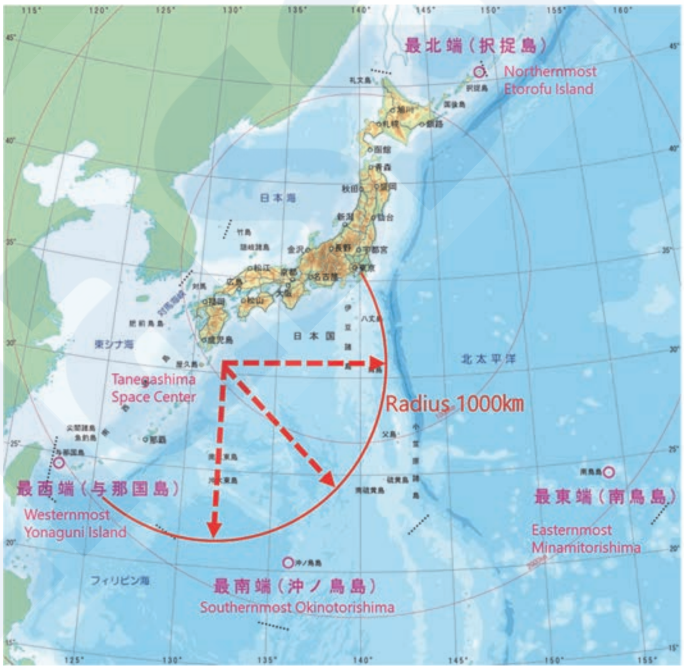

Fig. 2 Launch vehicle recovery area (proposed) (background figure [5])

Fig. 3 SpaceX Falcon 9 rocket [6)]

Fig. 4 SpaceX recovery ship (ASDS) [7)]

Fig. 5 SpaceX support ship (Go-Quest) [8)]

① Since the waters are comparatively calm off Florida, where SpaceX recovers launch vehicles, recovery is considered possible even with ships such as barges. In contrast, a ship with excellent seaworthiness in open water is needed in the seas around Japan, where heavy weather (wind and waves) may occur, depending on the season. Thus, it is necessary to adopt a large-scale ship which is not prone to pitching and rolling in swells at sea, or to use a general ship equipped with stabilizers (anti-rolling devices).

② SpaceX conducts launches of Starlink satellites [9)], etc. on a continuing basis, and therefore has stable, long-term opportunities for launches. Accordingly, it is possible to use a dedicated recovery ship, which is only used in launch vehicle recovery. On the other hand, opportunities for launch vehicle launches by JAXA are currently limited to a few times each year, so it will be necessary to consider maintenance management of the ship during periods when no launches are scheduled.

4. DEVELOPMENT CONCEPT OF RECOVERY SHIP

4.1 Required Functions of Recovery Ship

The functions required in the recovery ship in order to realize the overall concept of the reusable launch vehicle described above in section 2.2 were arranged as follows (Fig. 1).

(1) Basic functional requirements

① Function that enables sailing to the recovery zone
② Function for communication with the launch vehicle, land and the support ship
③ Function for keeping the ship's position in unmanned operation during launch vehicle recovery
④ Platform for launch vehicle recovery
⑤ Function for fixing/ensuring the safety of the launch vehicle after it lands
⑥ Accommodation function (living quarters) for the crew and other workers

(2) Functional requirements considering conditions specific to Japan

(a) Function for suppressing ship motion (stabilizers)
(b) Function as a multipurpose ship (conceivable possibilities include a dredging function [10), 11)], oil-spill recovery function, [10), 11)], hospital ship function, etc.)

4.2 Example of Recovery Ship Concept

JAXA is currently studying the trade-offs of ships that can realize the required functions. This section presents an example of the concept of a multipurpose ship which has functions such as transportation of hospital containers, etc. in addition to offshore recovery of launch vehicles, based on a combined dredging-and-oil recovery ship [10), 11)] (Fig. 6).

This ship was studied independently by the author, separate from the reusable launch vehicle plan in JAXA. If further study is to be carried out in the future, it will be necessary to study of its feasibility in terms of both ship rules, feasibility in terms of structural considerations, etc. in cooperation with shipbuilders and other related parties.

The following describes the features of this ship, corresponding to the required functions ① to ⑥ and (a) and (b) in section 4.1.

(1) A general ship is adopted to enable smooth sailing to the recovery zone (function ①). An azimuth-type thruster (full 360° horizontal rotation) is adopted, and the ship's position is maintained during launch vehicle recovery by using the thruster and the bow thrusters (function ③).

(2) During recovery, the recovery deck (11.5 (m) x 50 (m)) is mounted on the two sides of the ship's stern section, and an area of 50 (m) x 50 (m), which is necessary in launch vehicle recovery, is secured (function ④). During ordinary operation, the deck is stored on land so it does not hinder conventional ship operation. The equipment for fixing and ensuring the safety of the launch vehicle after landing is arranged near the recovery deck (function ⑤).

(3) The living quarters and the launch vehicle recovery deck are arranged in the ship's bow and stern areas, respectively (function ⑥). Visibility in the forward direction is secured by arranging the living quarters in the bow area. A gangway that allows vehicles to enter and leave the ship is provided on the port side of the living quarters, and a vehicle passage and parking area are provided under the living quarters. This improves accessibility by workers and when delivering launch vehicle and satellite equipment, which occurs frequently during launch vehicle maintenance work. Antennas for communication with the launch vehicle and support ship, etc. are installed on the weather deck above the living quarters (function ②).

(4) Anti-motion devices are mounted on the upper level of the living quarters, and the sides of the living quarters are sloped to reduce of the effect of crosswinds. A two-level structure with a space in the ship under the recovery deck of the hull is adopted so that crosswinds which strike the deck can pass through the space, thereby reducing rolling of the ship (function (a)).

(5) For multipurpose use, the ship has a dredging function (function (b)). A hopper door is arranged at the bottom of the dredged material tank. Side drag-type drag arms are adopted and arranged on both sides of the ship. To reduce the effect on the ship's trim condition when dredged material is discharged from the hopper door, the dredge material tank is arranged in the center of the ship. Furthermore, as an idea for reducing the damage to the living quarters in the unlikely event of a launch vehicle fire, the dredging tank is arranged between the launch vehicle recovery site and the living quarters. In case of a fire, the dredging pump is used in fire-fighting. During launch vehicle recovery, the ship's motion characteristics are controlled by loading the dredging tank with seawater.

(6) A large-scale portal crane is installed on the ship. This crane can be used as a multipurpose device, for example, for mounting the launch vehicle recovery deck, transferring the recovered launch vehicle to the quaywall, moving hospital-ship containers [12), 13)], etc.(function (b)).

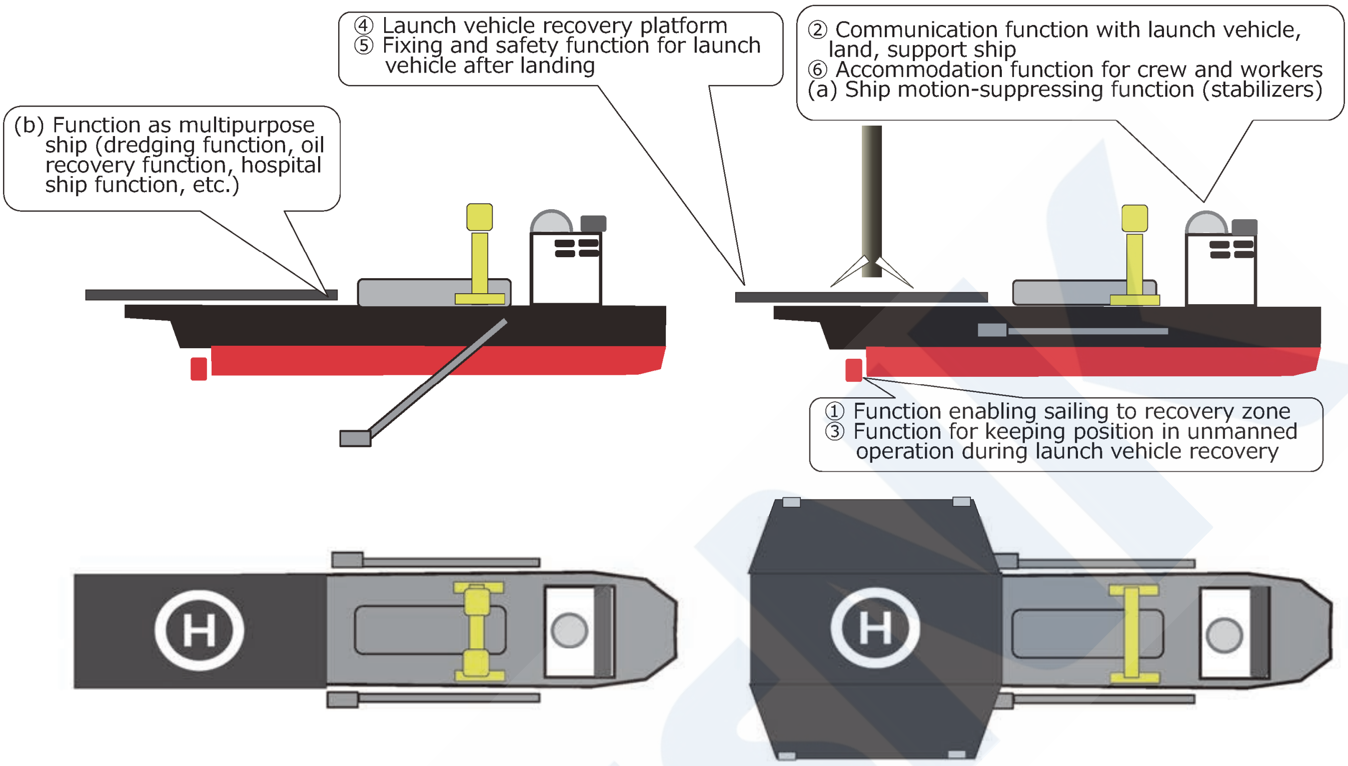

Fig. 6 Conceptual diagram of offshore recovery ship
(Left: during dredging, right: during launch vehicle recovery)

5. INITIATIVES FOR RISK ASSESSMENT OF RECOVERY SHIP

5.1 Policy of Initiatives

According to a book [14)] analyzing the cancellation of development of a Japanese-made regional jet, and the success of a small jet aircraft developed by an automobile manufacturer, the difference in the response to type approval has been pointed out as one perspective. As reasons for the success of the small jet, it was noted that the auto maker set up a base in the United States to carry out the procedures for type approval from the start, and deepened its technology exchanges with the US aircraft industry.

Because ships constructed by research and development institutes in Japan such as the Japan Agency for Marine-Earth Science and Technology (JAMSTEC), etc. receive approval from the ClassNK, JAXA is also planning to receive type approval from ClassNK for the first launch vehicle recovery ship to be constructed. To ensure approval by the Society, JAXA has adopted a policy of deepening technology exchanges with the Society from the start of development, and conducting research and development and risk assessment at the same time in parallel.

Table 1　Ship class rules and related regulations considered objects of study

Category	No.	Rules and regulations
NK Technical Rules and Guidance	1	Part A GENERAL RULES
	2	Part B CLASS SURVEYS
	3	Part C HULL CONSTRUCTION AND EQUIPMENT
	4	Part U INTACT STABILITY
	5	Part V LOAD LINES
	6	Part W NAVIGATION BRIDGE VISIBILITY
	7	Part D MACHINERY INSTALLATIONS
	8	Part GF SHIPS USING LOW-FLASHPOINT FUELS
	9	Part H ELECTRICAL INSTALLATIONS
	10	Part K MATERIALS
	11	Part L EQUIPMENT
	12	Part M WELDING
	13	Part N SHIPS CARRYING LIQUEFIED GASES IN BULK
	14	Part S SHIPS CARRYING DANGEROUS CHEMICALS IN BULK
	15	Part I SHIPS OPERATING IN POLAR WATERS, POLAR CLASS SHIPS AND ICE CLASS SHIPS
	16	Part O WORK-SHIPS
	17	Part P MOBILE OFFSHORE DRILLING UNITS AND SPECIAL PURPOSE BARGES
	18	Part R FIRE PROTECTION, DETECTION AND EXTINCTION
	19	Regulations for the Classification and Registry of Ships / Guidance
	20	Conditions of Service for Classification of Ships and Registration of Installations
	21	Regulations for the Issue of Statutory Certificates
	22	Rules for the Audit and Registration of Safety Management Systems / Guidance
	23	Rules for Safety Management Systems of Ships Not Engaged in International Voyages or Having Gross Tonnage of Less Than 500 Tons / Guidance
	24	Rules for the Audit and Registration of Ship Security Management Systems / Guidance
	25	Rules for the Inspection and Registration of Maritime Labour Systems / Guidance
	26	Rules for Inspection and Testing of Ship's Fittings
	27	Rules for Approval of Manufacturers and Service Suppliers
	28	Rules for Marine Pollution Prevention Systems / Guidance
	29	Rules for Safety Equipment / Guidance
	30	Rules for Radio Installations / Guidance
	31	Rules for Living Quarter Sanitation Equipment / Guidance
	32	Rules for Anti-Fouling Systems on Ships / Guidance
	33	Rules for Ballast Water Management Installations / Guidance
	34	Rules for Cargo Refrigerating Installations / Guidance
	35	Rules for Cargo Handling Appliances / Guidance
	36	Rules for Diving Systems / Guidance
	37	Rules for Navigation Bridge Systems / Guidance
	38	Rules for Preventive Machinery Maintenance Systems / Guidance
	39	Rules for Integrated Fire Control Systems
	40	Rules for Hull Monitoring Systems
	41	Rules for High Speed Craft / Guidance
	42	Rules for the Survey and Construction of Passenger Ships / Guidance
	43	Rules for the Survey and Construction of Ships of Fibreglass Reinforced Plastics / Guidance
	44	Rules for Marine Engine Emission Verification
	45	Guidance for the Approval and Type Approval of Materials and Equipment for Marine Use

Category	No.	Conventions
International conventions	1	MARPOL
	2	FSS code
	3	LSA code
	4	COLREG
	5	SPS Code (Code of Safety for Special Purpose Ships)
	6	IP Code (International Code of Safety for Ships Carrying Industrial Personnel)
	7	MODU Code (Code for the Construction and Equipment of Mobile Offshore Drilling Units)
	8	IMSBC Code (International Maritime Solid Bulk Cargoes Code)
	9	IMDG Code (International Maritime Dangerous Goods Code
	10	Polar Code (International Code for Ships Operating in Polar Waters)
	11	IBC Code (International Bulk Chemical Code)
	12	IGC code
	13	IGF code

Category	No.	Laws and requirements
Japanese laws	1	Ship Safety Law
	2	Regulations for the Carriage and Storage of Dangerous Goods in Ship
	3	Act on Prevention of Marine Pollution and Maritime Disaster
	4	Special Standards and Interim Standards
Others (Currently no regulations exist, but additional study is required)	1	Additional requirements for hospital ships
	2	Additional requirements for autonomous navigation ships
	3	Safety requirements related to launch vehicle recovery ships (requirements for fire-extinguishing and heat-resistant deck, etc.)

Category	No.	Standards
ロケット安全要求	1	JMR-001C System Safety Standard (*1)
	2	JERG-1-007 Safety Regulation for Launch Site Operation (*1)
	3	JERG-1-006 Launch Vehicle Development Safety Technical Standard (*1)
	4	NPR8715.3 NASA Procedual Requirements NASA General Program Requirements　Chapter 2, System Safety
	5	MIL-STD-882 Department of Defense Standard Practice for System Safety

(*1) See https://sma.jaxa.jp/techdoc.html

5.2　Survey of Ship Class Rules

(1) Purpose

Among the objects of study, assuming the combined dredging-and-launch vehicle recovery ship described in section 4.2, the applicable rules in case functions such as a dredging ship, hospital ship, etc. are to be added, and the issues and measures for obtaining approval under those rules, were arranged. The investigation of the rules on the rocket side was also carried out at the same time in parallel, and the total image of the applicable rules was arranged.

(2) Results of study

Table 1 shows the overall image of the rules that were the object of this study. It was found that a response to the ship class rules is possible by responding in accordance with the design and construction plan. However, if the ship type is changed thereafter, a response beginning from confirmation of the applicable rules is necessary. Furthermore, as items which must be confirmed after the specification and operation of the launch vehicle are finalized, several other issues were also found, as outlined below.

① In case offshore recovery of launch vehicles is to be performed by unmanned operation, it is necessary to determine whether unmanned operation limited to keeping the ship at a fixed position is sufficient, or fully-autonomous operation is required.

② It was found that advance training for JAXA and manufacturer's staff members will be necessary if they are to embark on recovery voyages on the recovery ship. Referring to the example of ships owned by JAMSTEC, it is also necessary for JAXA to prepare a training manual.

③ If the multipurpose launch vehicle recovery ship is to be used as a hospital ship, a substantial increase in construction costs is possible if medical activities are to be carried out onboard, as the ship's specification will be similar to that of a passenger vessel.

④ In the future, study as a total launch vehicle system (launch vehicle + ship) will be necessary. In the future, in parallel with work to clarify the specifications of the launch vehicle at that time, it will also be necessary to arrange the rules on the launch vehicle side again through consultation with the JAXA Launch Safety Group, etc.

⑤ It is necessary to arrange the relationship between the environment at the time of launch vehicle landing (shock, heat, combustible gases) and pressure vessels carried on the ship. A detailed study of launch vehicle-related hazardous substances (launch vehicle fuel, liquid oxygen, hydrazine, etc.) loaded on the ship is also necessary, including methods of handing those substances.

6. FUTURE ISSUES

6.1 Study on Feasibility of Recovery Ship

Since the ship is currently in the conceptual stage, as noted in section 3.2, a feasibility study in cooperation with shipbuilding engineers is necessary. A large number of studies will be required, such as study of the type of ship to reduce ship motion during launch vehicle recovery, the strength design and heat resistance design of the launch vehicle recovery deck, etc. On the other hand, technical study for launch vehicle recovery is also needed. This study also includes numerous items, for example, study of a function for safely securing the launch vehicle, a function for ensuring safety, a function for unmanned operation, etc.

In addition, it is necessary to assess the life cycle cost (LCC) aspect of the ship. Although use in dredging, launch vehicle transportation, as a hospital ship, etc. have been proposed as applications when the ship is not being used in launch vehicle recovery, these were only mentioned as possibilities. Since use as a multipurpose ship has the demerit that the ship's structure and operation become more complicated, it is possible that a ship with more narrowly-focused functions may be a better option, considering the actual operation costs and the desires of the company that will operate the ship.

6.2 Use as a Platform for Solving Space- and Ship-Related Problems

To realize a launch vehicle recovery ship, the cooperation of both space technology and ship and marine technology is essential. By developing the appeal possessed by space technology and the high technological capabilities of ship technology in combination, it may be possible to use the launch vehicle recovery ship as a platform for solving the problems faced by the respective industries.

According to the literature [16)], the problems for the ship industry include maintenance of government ships and the development and popularization of gas-fueled ships for realizing carbon neutrality. Demonstration of autonomous operation technologies [17)] and efforts such as ICT dredging [18)] are also progressing. By utilizing the launch vehicle recovery ship as a platform for demonstrations of those technologies, the ship will become a platform that appeals to an even larger number of the nation's citizens, and can be expected to broaden public understanding of the ship industry.

In the space industry, further improvements in performance and reliability and lower costs are demanded in response to intensifying competition involving venture companies in recent years. Because SpaceX in the United States has already applied reusable launch vehicles practically and has a proven track record with this technology, it will not be sufficient if JAXA simply continues efforts along an extension of conventional lines; if it does so, there is concern that the differences between JAXA and various other countries will grow wider. From this viewpoint, it is necessary to utilize the recovery ship in various applications so as to create new business opportunities and increase total profitability.

In Japan, many industries have high technological capabilities, including the shipbuilding and marine equipment industries and the shipping industry. Taking advantage of Japan's technological superiority and cultural background, we hope to create new ideas through discussions with various industries.

ACKNOWLEDGEMENT

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REFERENCES

1) Y. Kado: Ship Recovery of Reusable Rockets, Marine Engineering, Vol. 59, No. 1, Jan. 2024
2) Ministry of Education, Culture, Sports, Science and Technology, Space Utilization Subcommittee, Investigative Study Subcommittee on Future Space Transportation System: Meeting materials, 2020.
3) Ministry of Education, Culture, Sports, Science and Technology, Research and Development Bureau, Space Development and Utilization Division: Study Group Summary of Roadmap for the Realization of an Innovative Future Space Transportation System, 2022.
4) Ministry of Education, Culture, Sports, Science and Technology, Research and Development Bureau, Space Development and Utilization Division: Study Group Interim Summary of the Roadmap for the Realization of an Innovative Future Space Transportation System, 2021.
5) Geospatial Information Authority of Japan: Longitude and Latitude of Japan's East, West, South and North Extremities, https://www.gsi.go.jp/KOKUJYOHO/center.htm, (accessed Apr. 1, 2024)
6) https://www.spacex.com/, (accessed Apr. 1, 2024)
7) https://spacexfleet.com/go-quest/, (accessed Apr. 1, 2024)
8) https://en.wikipedia.org/wiki/Falcon_9, (accessed Apr. 1, 2024)
9) https://www.starlink.com/, (accessed Apr. 1, 2024)
10) Drag-Suction Dredger: The Japan Workvessel Association (JWA), (accessed Apr. 1, 2024)
11) H. Kato: Introduction to Dredging and Oil Recovery by Combined Drag-Suction Dredger and Oil Recovery Ship, Marine Engineering, Vol. 53, No. 6, Nov. 2018
12) Cabinet Office, Government of Japan: Study Group on Utilization of Hospital Ships, https://www.bousai.go.jp/kaigirep/ship/index.html, (accessed Apr. 1, 2024)
13) Cabinet Office (Disaster Prevention): Investigation and Study Report on Multipurpose Ships (Hospital Ships) during Fires, Mar. 2013
14) T. Sugimoto, H. Fujimoto and S. Yumae: The Rise and Fall of *Monodzukuri*, Nikkei BP, Nikkei Publishing Co., Ltd. (Mar. 5, 2024)
15) Ministry of Land, Infrastructure, Transport and Tourism (MLIT): Strengthening the International Competitiveness of the Shipbuilding Industry,https://www.mlit.go.jp/maritime/maritime_tk5_000014.html, (accessed Apr. 1, 2024)
16) The Nippon Foundation: MEGURI2040 Fully Autonomous Ship Program, https://www.nippon-foundation.or.jp/who/about/history/60years/1-topics-1-2, (accessed Apr. 1, 2024)
17) T. Oyama: Execution of ICT Utilization Works (River Dredging), Kanto Regional Development Bureau, Arakawa-Karyu River Office, Onagigawa Branch Office, https://www.ktr.mlit.go.jp/ktr_content/content/000746669.pdf, (accessed Apr. 1, 2024)