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Unmanned ships – maritime transport of the 21st century

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Abstract

Unmanned, remotely or autonomously ships are the fastest growing new technology in maritime transport in recent years. The design of unmanned vessels envisions clean, emission-free electric propulsion. The costs of building physical models and target vessels are high, but the expected benefits are generating increasing interest in such vessels. This article presents the current state of research in the field of unmanned ships and the technical, legal and administrative problems that need to be solved in order for these ships to be used by the general public.

Introduction

Transport has been one of the fastest growing sectors of the economy for many years. The greatest technological achievements can be observed in land and air transport. On the other hand, maritime transport, which is responsible for about 80% of the world's transported cargo, has for decades, been very conservative in terms of implementation of new, breakthrough technological solutions. New systems installed on ships after World War II were aimed at improving safety (navigation systems) and reliability (more performance and more efficiency marine combustion engines, automation, and control of propulsion systems). Only at the beginning of the 21st century did the design of new technological solutions start; the implementation of which in maritime transport was stimulated by the necessity for:

- improvement and further increase of maritime transport safety – analyses of maritime accidents and catastrophes indicate that their cause is not a failure of ship equipment but only human error (depending on the type – collision, shallowing, fire – man is responsible for 80% – 96% of all accidents (Chauvin et al., 2013; Herdzik, 2014; Cordon, Walliser & Mestre, 2015);
- reduction of ship operating costs – about 20% – 30% of these costs is the maintenance of the crew and shipowner's services dealing with crew;
- environmental protection – although maritime transport accounts for about 3% of global CO_2 emissions to the atmosphere, it is expected that new ship designs will have completely ecological propulsion systems;
- improvement of other indicators influencing the economic side of maritime transport – a new hull construction with a smaller weight will result in a better use of ship displacement;
- more accurate ship guidance on shipping lines, which can lead to reduced energy expenditure, reduced voyage time or improved punctuality of entry to the port of unloading.

Transport, including maritime transport, is a very important factor in the development of the economy, which often forces its rapid development, sometimes with specific requirements adapted to a specific economic situation. The above-mentioned factors will therefore force such technological development in maritime transport that it will be able to meet the requirements resulting from the development of the world economy. Unmanned ships are such a new technological solution in maritime transport. The aim of the analyses in this article is to present the current state of research and experimental work on the construction of unmanned ships and their effects considering the technical, legal, and administrative problems to be solved before allowing the operation of unmanned ships.

Development of technology for autonomous unmanned ships

The first unmanned ships

At the beginning of the 20th century, N. Tesla developed a remote wireless control system (radio waves) and built the world's first model of a remote-controlled ship shown in Figure 1 (Turi, 2014; Chojnacki & Pasek, 2017). However, too weak technological development at that time meant that such projects were not implemented and further developed.

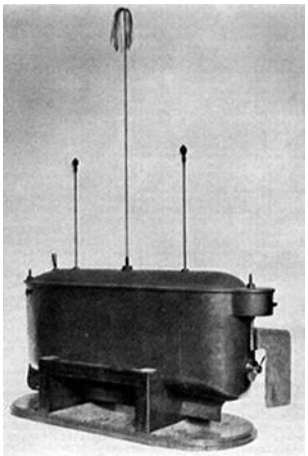

Figure 1. A prototype, remote-controlled Tesla boat (Turi, 2014)

In 1916, the Ruston Proctor AT remote-controlled aircraft was developed in the UK, but the technology of the time did not allow the construction and use of remote-controlled aircraft without pilots. In the 1920s, research on small, unmanned flying objects "Queen Bee" was started as a lure for anti-aircraft artillery. In 1936, the term "drone" was used for flying objects (Udeanu, Dobrescu & Oltean, 2016). In the 1950s, Northrop Grumman began researching autonomous airplanes for mainly military purposes (McAndrew, 2019).

Development of unmanned ships technology

In view of the many technical problems and potential risks that may arise during the operation of ocean-going vessels, the development and implementation of unmanned ships technologies will take place in stages:

- intelligent ship;
- unmanned, remote-controlled;
- unmanned, autonomously controlled:
  - small experimental vessels operating in closed waters or in coastal waters;
  - ultimately, ocean-going vessels.

Intelligent ship

Currently, it is a typical, classic manned transport vessel with a diesel engine equipped with an intelligent system responsible for optimization of all ship equipment and processes (loading and unloading in the port, stability, and maritime properties, forecasting the route of navigation and anti-collision maneuvers, and optimization of propulsion system parameters). There are crew on board and the final decisions are made by the captain. Computer system installed on the ship collects all parameters related to the operation of the ship and environmental parameters in real time. It also has guidelines on the type based on the developed algorithms which calculates the optimal operating parameters of the ship. In the future, such a vessel may be remotely controlled and operated without a crew.

First intelligent very large ore carrier iVLCC (intelligent very large ore carrier), was designed, built and classified by DnV GL (China, December 2018, L_C = 362 m, B = 65 m, H = 30.4 m, T = 23 m, P_N = 399,999 DWT) (Offshore Energy, 2018). The ship is equipped with an intelligent computer system to optimize the operation of all devices and ship processes including loading, unloading, shipping route, traffic parameters and propulsion system of the ship.

Unmanned, remote-controlled ship vessel

Unmanned ships are equipped with a propulsion system and computer systems enabling remote (from land-based centers) control and monitoring of its movement and operational parameters. The first tests were carried out on crew vessels adapted to remote control tests.

The ship, Highland Chieftain (L = 79.45 m, B = 16.8 m, T = 6.0 m) (Strefa Portowa, 2017), built in 2013 in the Gdansk shipyard Remontowa

Shipbuilding, has a Dynamic Positioning System (DSP). The DSP system is supplemented with an additional software – Wartsila Nacos Platinum – enabling remote control. The first tests were carried out in August 2017 in the North Sea.

Figure 2 shows an experimental model of an unmanned ship – USV MAXLIMER, which sailed in May 2019 from Tallesbury (UK) through the English Channel to Ostend (Belgium) and back (gCaptain, 2019). During the cruise, it was remotely controlled and monitored from the land-based center.

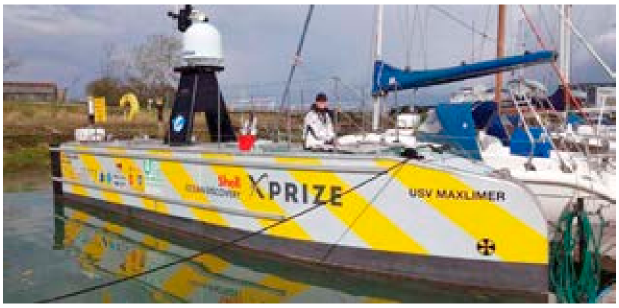

Figure 2. Experimental model of an unmanned aerial ship USV MAXLIMER (L_C = 11 m)

Unmanned autonomous ships

The Maritime Autonomous Surface Ship (MASS) is to be controlled and supervised by an on- board computer with appropriate software, without human intervention. Autonomous control and supervision are to be carried out throughout the entire process of ship operation – from loading the ship in the port, through maneuvers associated with leaving the port, cruising through the open sea, entering the port of destination and unloading.

The first projects, however, assume that the ship will be monitored from the land-based center and in case of failure or errors in the control, the control over the ship will be taken over by the operator from this center. Even if autonomous control systems are tested and allowed to be installed on a commercial vessel, it is most likely that entry into port and maneuvers in port will be carried out with the help of a remote control or in the presence of a pilot.

Projected implementation into service of unmanned aerial ships

The forecast of research, development, and implementation into operation of unmanned autonomous vessels according to Rolls-Royce (IMO, 2018) is presented in Figure 3.

However, given the lack of adequate legislation, the high costs of research and testing, the deadlines

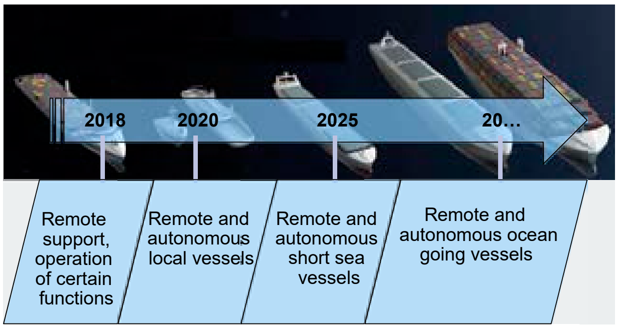

Figure 3. Forecast of research, development, and commissioning of unmanned autonomous vessels (IMO, 2018)

for the implementation of individual solutions (Figure 5) are likely to increase.

Levels of autonomy of vessels

The lack of current maritime regulations allowing for the operation of unmanned vessels, high potential risks resulting from the possibility of ship collisions at sea, and the lack of sufficient experience in the construction of control systems and in the operation of unmanned vessels mean that the implementation of autonomous controlling will take place in stages. Various maritime institutions have developed their own scales of autonomy levels, (IMO, 2018).

As can be seen from the table, the preparation of the provisions concerning the levels of autonomy of unmanned ships and their equipment to achieve these levels is mainly the responsibility of Classification Societies, maritime institutions, and research centers. The Polish Register of Shipping (PRS) is also involved in the design and construction of control systems, models of unmanned vessels, and in the future, supervision over the construction of real unmanned vessels.

The autonomy levels are very general and abbreviated. In the relevant legislation of the organization, e.g., BV or LR, there are fuller explanations or lists of additional navigation equipment for a certain level of autonomy. A more complete description of the autonomous control system's functionality and human participation in the decision-making process can be found in e.g., the Sheridan scale (AAWA, 2016).

The International Maritime Organisation (IMO) is also working to prepare legislation on unmanned ships and to harmonize levels of autonomy. In December 2018, at the 100th session of the Maritime Safety Committee, the IMO proposed 4 levels of autonomy (ship with automated processes and decision support, remotely operated ship with seafarers on board, remotely operated ship without seafarers on board, and fully autonomous ship).

The presented autonomy levels explicitly suggest that, before fully autonomous vessels are built, manned vessels with varying levels of autonomy during their operation will be built:

- in the first phase, because of too little experience and perhaps imperfections of algorithms controlling the motion of the ship,
- due to various emerging threats or difficult tasks during ship operation (e.g., passage through areas with many ships or entry into ports).

Therefore, land-based monitoring centers and, if necessary, remote control centers for ships will be required for the operation of unmanned vessels.

The decision to apply an appropriate level of autonomy to a given ship, task or area will depend mainly on the level of complexity or safety that must be maintained in the completion of a given task (AAWA, 2016).

The first unmanned ships will be able to carry out only relatively simple tasks and make simple decisions on their own, so in case of more difficult, less obvious decisions, human participation will be needed. Another reason for the necessary human participation is dangerous situations such as passing of ships. Even when performing a routine route on the high seas, where automatic control should be sufficient, it is assumed that the system will inform the operator on land in exceptional situations about the need to take over the control or make a decision related to an exceptional situation.

In the future, more advanced collision avoidance systems will be developed, which will solve more and more contactless situations, in accordance with COLREG rules and good maritime practice, without the involvement of the land-based operator. Communication systems between unmanned and manned vessels will be developed, which may significantly reduce the burden on land-based (remote) operators, who will be able to supervise more vessels at the same time and increase maritime safety.

The state of research on autonomous unmanned ships

The first studies on the possibility of building unmanned autonomous vessels began at the beginning of the 21st century.

In 2013, Rolls-Royce Marine began work on the design of the autonomous ship. The project Advanced Autonomous Waterborne Applications Initiative (AAWA) was launched, which aims to develop a project and technical solutions (navigation systems, safety, monitoring, collection, and processing of operating parameters) to enable the construction of autonomous ships. Within the AAWA project, a virtual center for controlling the fleet of unmanned vessels was also developed (gCaptain, 2016).

Currently, research and experimental works on unmanned ships are carried out in two directions:

- construction and testing of remote systems and then autonomous control systems on existing crew vessels (most often these are small car-passenger ferries operating over short distances);
- design, construction, and experimental testing of unmanned ships – in the first stage these are the physical models of vessels of ten meters in length, followed by the construction of the target unmanned ships.

At the same time, design and experimental work is being carried out on additional systems for unmanned vessels: land-based monitoring, loading and unloading centers in the port, and port computerized systems for unmanned vessels.

Examples of conducted research on autonomous control systems installed on crew vessels:

- tests of autonomous control on the car ferry Falco (L = 53.8 m, B = 12.3 m) – Finland, December 2018 (PortalMorski.pl, 2018) – the ferry performs autonomous maneuvers and is supervised by the operator from the land center in Turku;
- Suomenlinna II autonomous ferry control tests – Finland, December 2018 (GospodarkaMorska.pl, 2018) – monitored trials from the Helsinki land center;
- tests of autonomous controlling on the supply vessel SeaZip 3, the Netherlands, in the North Sea – March 2019 (CTV Seazip 3, 2019).

Examples of designs and studies carried out for new unmanned autonomous ships:

- The Re-Volt – remote-container ship with electric drive (Norway) (DNV GL, 2019) shown in Figure 4 – designed by DNV GL from 2017, is to carry 100 TEU;

Figure 4. Visualization of the experimental vessel Re-Volt (L = 60 m; B = 14.5 m; T = 5.0 m; V = 6 knots, range 100 Mm) (DNV GL, 2019)

Figure 5. The model of the vessel "Yara Birkeland" for research and testing and autonomous container ship built in 2020 (120 TEU, L = 79.5 m, B = 14.8 m) (GospodarkaMorska.pl, 2020)

- Ship Yara Birkeland – unmanned container (Norway) designed from 2017 (Kongsberg, 2017) shown in Figure 5; model tests in 2018 and ship built in 2020 (GospodarkaMorska.pl, 2020).

Implementation of the Yara Birkeland project:

- ship model design, construction, and testing (2017–2018);
- construction of the target container ship, operation with crew (from 2019);
- equipping the container ship with an autonomous system, experimental exploitation for 2 years, systematic crew reduction and control from land-based centers).

In addition to the presented projects, other projects are being implemented, such as the ShippingLab Project (Denmark), the SeaShuttle Project (Norway and the Netherlands), and the Autoship Project (United Kingdom R-R and Norway Kongsberg).

First, Polish, experimental model of the autonomous ship

In January 2018, at the Maritime Academy in Szczecin, a design of an unmanned, autonomously controlled container ship (bulk carrier) was made (see Figure 6).

Figure 6. Visualization of the design of an unmanned, autonomously controlled container vessel (L_C = 78.75 m, B = 11.10 m, T = 4.33 m, ∇ = 2500 m^3)

Figure 7. Launching and remote-controlled tests of an unmanned vessel model

Figure 8. Tests of navigation systems and remote telemetry in the North East Marina Szczecin

A model of unmanned ship, presented in Figure 7, in 1:25 scale was built to test the control system and propulsion system. Launching and remote-controlled tests of a vessel model in open water were carried out in October 2018, in the Maritime Rescue Training Centre AMS.

Then, after equipping the model with navigation systems (GPS, electronic compass) and systems for recording and monitoring the parameters of the propulsion system, in June 2019, further tests (Figure 8) were carried out in the North East Marina Szczecin.

Currently, the model is equipped with an on-board computer and software for autonomous control. The trials of autonomous control (without remote control) are still scheduled for 2019.

The first test of the computer program (shown in Figure 9) for automatic control of the ship's model was carried out on 18 December 2019 at "Głębokie" Lake in Szczecin.

Technical and legal problems related to the construction and operation of unmanned ships

Technical problems

In all projects developed and implemented, it is emphasized that unmanned (remote-controlled and autonomous) vessels are to be completely clean and emission-free (no exhaust gas, noise or leaks polluting the marine environment). The ideal solution to meet these requirements is electric propulsion (hybrid drives – internal combustion engines and electric engines on board a ship are transition stages to electric propulsion). Electric propulsion has many advantages over combustion propulsion:

- no exhaust gas;
- easy to operate, easy to start;
- high reliability;
- better drive characteristics (full power can be achieved quickly, torque is less dependent on speed);
- easy to adapt to remote control and monitoring.

Starting the design work, and then the construction of autonomous ships forces the solution of various technological problems, such as:

- electric unmanned propulsion systems, in the long term, high power;
- electrical supply installations, in the long-term high power and high voltage;
- very large capacity batteries;
- fuel cells such as hydrogen);
- photovoltaic cells with high energy efficiency;
- global remote control and monitoring systems;
- land-based control and monitoring centers;

a) b)

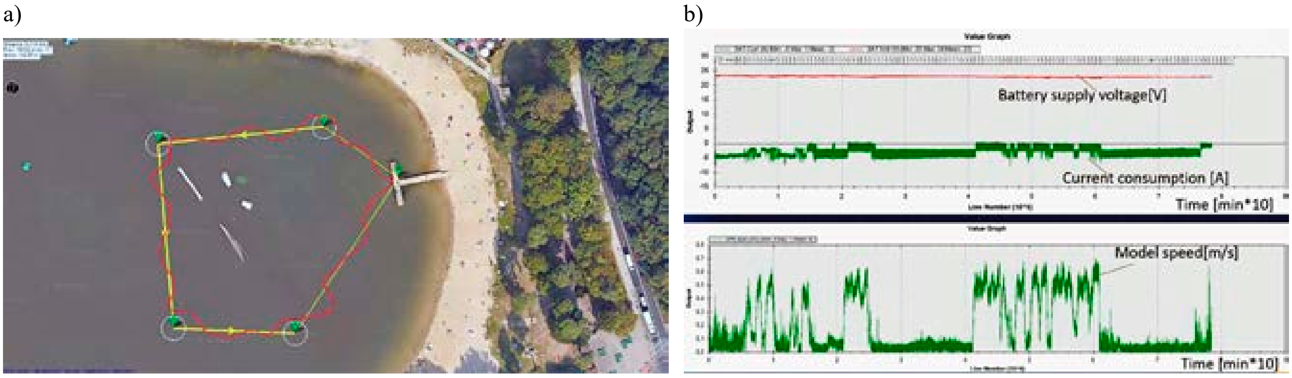

Figure 9. The set and actual route of movement of the model (a) and an exemplary recording of parameters during tests (b)

- very low latency and interference resistant radio communication systems, including cybercrime;
- navigation systems with high-speed information transfer;
- new materials for the construction of the hull of the ship in order to reduce its weight, which results in a reduction of propulsion power;
- new structural solutions for the hull of the ship and its equipment – although these are to be unmanned ships, it must be possible for a person to board (e.g., for control purposes) and participate in rescue operations;
- port infrastructure suitable for unmanned ships (mooring, unloading, loading).

Legal and administrative problems

The operation of unmanned ships requires completely new legal regulations concerning maritime law, maritime administration, classification and supervision over shipbuilding, ship and cargo insurance, and IT security. Apart from the technical aspects, many other legal regulations requiring adjustment of the existing regulations or development of new ones concerning, among others:

- the possibility for an unmanned vessel to participate in the rescue of goods and rescue at sea (SOLAS Convention);
- the inspection of port or other services on an unmanned ship;
- regulations governing the construction and equipment of unmanned ships;
- the authorization of the placing in service of unmanned ships;
- procedures and protocols for the exchange of information between vessels (manned and unmanned) at sea;
- the role and responsibility the unmanned ship operator from the onshore center will have;
- liability for damaged cargo or sinking of an unmanned aerial vehicle (shipowner, SBO operator);
- seaworthiness and liability of the ship's insurer (if the ship is not seaworthy, the insurer is not liable for damages);
- the adaptation of existing maritime law conventions, e.g., UNCLOS – (qualified crew) to unmanned ships or COLREG (Prevention of Collisions at Sea);
- appropriate radio monitoring and listening on unmanned ships;
- whether the unmanned vessel will be considered a vessel with reduced maneuverability (problem of way out);
- whether there will be a mandatory pilotage on an unmanned ship, as is the case in some ports, who may be responsible for pilot errors.

Development prospects and use of unmanned ships

In the first period of entry into service of unmanned ships, these will be the following:

- small delivery container ships, also carrying bulk cargo – for container ships there is a relative ease of autonomous loading and unloading in a port;
- small delivery tankers, but not carrying dangerous goods;
- short distance car-passenger ferries (ferries without hotel staff);
- port and technical vessels, e.g., fire-fighting vessels;
- inspection, monitoring and testing bodies, e.g., hydrographic, environmental protection, and coastline or bottom mapping.

After the development of autonomous control technology and the development and ratification of legal regulations, ocean-going unmanned vessels will appear (in about 15–20 years).

A separate and very prospective area of application of unmanned floating objects is the navy – ships are not subject to civil ship conventions.

For military purposes, small, unmanned ships may be used, floating on the surface or under the surface of water:

- reconnaissance and intelligence;
- tracking other ships;
- monitoring the movement of ships and ships;
- in the future of the armed forces.

Summary and conclusions

1. Maritime transport in the near future, for the most part, will be operated by unmanned vessels because of:
   - reduction of operating costs and
   - environmental protection (electric drives), reduction of accidents and catastrophes at sea.
2. Research, design, and construction of unmanned ships has accelerated significantly in the last two years:
   - the shipbuilding industry has for centuries been a very conservative and traditional branch of industry, there have been too few innovative changes in relation to other forms of transport and management of transport means;

- research works involve developed so-called "maritime" countries (represented by companies, research centers, classification societies);
- research and development of prototypes of unmanned ships is expensive – government institutions have a large financial share in this research;
- the first manned intelligent ships are already operating, remotely controlled ships are already operating, and autonomous controlling is being tested.

3. The development of research and design work on unmanned ships requires solutions to many problems of a nature: design, construction, propulsion, power supply, control, and information technology.
4. Small delivery vessels (e.g., container ships, tankers), short distance ferries, technical, port, and auxiliary vessels – operating in internal waters – will be operated most quickly.
5. The first fully autonomous vessels will be operated in open waters once the relevant regulations and maritime conventions have been developed and ratified.
6. The Polish shipbuilding industry, in order to be at the forefront of the world, must carry out research and design works concerning unmanned ships.
7. The Polish Navy has a wide range of applications for unmanned craft.

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