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RETROFIT SOLUTIONS TO ACHIEVE 55% GHG REDUCTION BY 2030

Risk assessment of the PALS and mitigation plan to ensure safety at sea leading to AIP

WP 5 – Air Lubrication System
Task 5.3 – Safety, Risk and Compliance
D5.3 – Risk assessment of the PALS and mitigation plan to ensure safety at sea leading to AIP
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Executive Summary

The **RETROFIT55** project aims to reduce greenhouse gas emissions by 55% by 2030 through retrofit solutions. WP5 focuses on integrating PALS into maritime vessels to improve energy efficiency and reduce fuel consumption. PALS uses the venturi effect to ingest air, reducing compressor usage and minimizing hull friction. PALS integration is anticipated to enhance fuel efficiency, lower GHG emissions, and meet international regulations.

The Approval in Principle (AiP) requires a systematic approach and risk assessment per RINA GUI015 to identify and control potential hazards or failures affecting novel technology. The goal is to mitigate any adverse effects on people, the environment, or the ship. Risk assessments recommend safeguards and determine if risks are adequately mitigated. Engineering analyses ensure the design meets general service requirements. All new technologies must be approved according to existing rules and regulations before installation on vessels. A detailed analysis of regulatory frameworks and certification schemes from Class Societies is crucial for the project's impact therefore a AiP is issued.

Since the classification societies have standardized the requirements for this system, there is no need for a risk assessment and therefore for an AiP considering the technology no longer a novel technology. The existing provisions of Class rules can address the remaining passive components, and the system's compliance with these standards ensures its operational feasibility and safety

This Deliverable will outline the process and result of the Class AiP of the PALS, focusing on verifying that this new technology is feasible, fit for purpose, and safe throughout the ship's lifecycle by adhering to defined rules and regulations.

1 Introduction

The Air Lubrication System (ALS) is an energy-efficient technology acknowledged by the International Maritime Organization (IMO). It aims to assist the maritime industry in reducing emissions by decreasing the fuel requirement for ships.

Within RETROFIT55, ALS integration is studied as a retrofit solution to reduce vessel carbon footprints.

By introducing low-viscosity fluid into the hull's boundary layer, ALS reduces hull friction and propulsion needs. Notable results have been observed in vessels with full hull forms and calm water conditions. Various types of ALS have been proposed to reduce drag friction by injecting compressed air beneath the hull to form a thin layer of air.

While reduction of propulsion power demand is anticipated, energy savings could be affected by the power needed for air compression. Therefore, the lubrication system studied in the project is Armada's recently developed Passive Air Lubrication System (PALS).

PALS is designed to reduce power consumption associated with air bubble production. Air is ingested in the system by exploiting water's kinetic energy. Water inlets are located below the waterline at the ship's bow and utilise the **venturi effect**, which is the decrease in fluid pressure that occurs when a moving fluid accelerates as it flows from one section of a pipe to a narrower section.

Implementing PALS can result in significant cost savings for shipping companies by reducing fuel consumption. The reduction is achieved by decreasing skin friction on the underwater hull and reducing the electrical power needed to produce air bubbles. The system's low maintenance requirements ensure minimal downtime and operational interruptions, making it an economically viable solution. The energy saving achieved with PALS supports compliance with international regulations to reduce maritime pollution, thereby helping operators avoid potential costs for exceeding the target set by the IMO GHG emission reduction pathway.

As awareness and adoption of such technologies grows, PALS plays a crucial role in the future of maritime transportation.

2 Approval in Principle

2.1 Background of AiP

The methodologies and the process of "Class Approval in Principle" (AiP) and all certification schemes have already been presented in D4.5. Although D4.5 is focused explicitly on the AiP of wind-assisted propulsion systems, the principles for assessing compliance remain the same, with the final scope of verifying that any novel technology is feasible, fit for purpose and safe throughout the ship lifecycle.

RINA GUI.19 *"Guide for Approval in Principle of Novel Technologies*" [1], also generally applies to PALS technology.

For easy reference, the key aspects of AiP are hereby briefly recalled.

Novel technologies include components, equipment and systems that are not proven, encompassing the application of both proven technology in a new environment and unproven technology in a known environment.

Since novel technologies are generally not adequately covered by established codes and procedures, AiP requires a systematic process of verification that includes an examination of the design procedure and engineering analyses, potentially ranging from conceptual design to complete design, sometimes including the identification of testing programs on full-scale prototypes.

The AiP verification should identify any novel element or novel application of known elements, and the procedure is developed in steps:

- description of the technology to be qualified;
- detailed assessment of interface requirements with the ship, operational conditions and limitations, and specific safety criteria related to the novel technology;
- definition of the functional requirements of novel technology;
- risk assessment - according to the methods described in the RINA GUI.15 *"Guide for Risk Analysis"* [2] - to identify, rank and control hazard and/or failure modes potentially affecting the novel technology;
- engineering analyses – possibly supported by tests on prototypes - to demonstrate that the design of the novel technology is fit-for-service in terms of functionality, safety, reliability, availability and maintainability.

A formal statement of fitness-for-service can be acquired through the Technology Qualification Process (TQP), which may result in a certificate, class notation, or other equivalent documentation (refer to the section below for more details on TQP. In cases where engineering analyses and prototype tests are unavailable, the feasibility of innovative technology may be demonstrated through alternative methods, provided that appropriate justifications are given.

The typical documentation to be produced includes:

- design criteria;
- applicable regulatory framework;
- detail drawings and schemes;

- technical specifications;
- report on the engineering analyses to show that all requirements for the intended service are met by the design;
- risk assessment reports, as needed.

The outcome of everything mentioned above is an official statement supported by relevant documentation, such as a certificate or equivalent document. This is issued after having evaluated the above-mentioned documents. The AiP statement will confirm that the novel technology complies with the general requirements for its intended service.

The systematic approach for AiP of new technologies not covered by existing codes is detailed in the RINA Guidelines GUI19 *"Guide for Approval in Principle of Novel Technologies*" [1] or equivalent. Risk assessment for AIP should follow the methods in RINA GUI015 *"Guide for Risk Analysis*" [2], and GUI23 *"Guide for Failure Mode and Effect Analysis (FMEA)"* [3] or equivalent.

Demo prototypes installed on board need at least an AiP. Submit the required documents for consideration and approval to a Class Society, which will verify compliance with rules, regulations, and Standards. After AiP, the integration of the new technology onboard is assessed.

As mentioned, novel technologies lack coverage by existing codes and procedures. They require a TQP to ensure they meet fitness-for-service standards. Without a documented track record for specific applications, both new technologies in known environments and known technologies in new environments fall under the novel technology concept.

Novel technologies are deemed suitable for service when evidence shows they meet all the requirements of functionality, safety, reliability, availability, and maintainability outlined in the Technology Qualification (TQ) basis, including specified criteria, boundary conditions, and interface requirements. The qualification process involves a systematic and documented examination of the design, engineering analyses, and testing programs.

Steps for evaluating the new technology are as follows:

- the new technology is divided into subsystems and components using system schematics and P&ID. The focus is on the manufacturing, installation, and operation of subsystems and components;
- the potential innovation of each subsystem and component is assessed;
- the challenges and uncertainties of the new technology are identified.

The TQP is founded upon the following main steps:

- conducting risk and safety assessments to identify, prioritize, and mitigate potential failure modes that could affect the operational integrity of the novel technology;
- engineering analyses confirm the novel technology meets all specific service requirements;
- tests and measurements to prove the novel technology meets its intended requirements;
- a functionality assessment ensures that functional requirements, safety, reliability, availability, and maintainability criteria are met.

The initial step involves assessing the risk and safety aspects of the new technology using established techniques to ensure compliance with regulations. The focus is on potential events affecting the operational readiness of the new technology as well as its interfaces with ship systems based on proven technologies.

The risk assessment is typically carried out as follows:

- hazards are identified;
- risks are assessed against the defined acceptance criteria and interfaces with other ship systems;
- risk control options (RCO) are defined. In detail, strategies of prevention, mitigation, or a possible combination of them are built up in case the risk is to be reduced according to the ALARP principle to settle on acceptable levels;
- the overall study is documented.

Potential hazards for risk assessment include:

- extreme weather, influencing maximum ship motions, accelerations, inclinations, temperatures;
- mechanical damage, possibly leading to liquid/gas release or progressive ship flooding;
- fire and/or explosion;
- release of flammable or toxic gases;
- release of cryogenic liquids or gases;
- loss of electrical power supply with a negative impact on ship essential services;
- failures related to single or possibly multiple systems on-board.

The systematic application of TQP results in technical outcomes:

- description of the technology to be qualified together with its boundaries;
- detailed information on the operational conditions and corresponding constraints related to the novel technology;
- definition of the functional requirements the novel technology deals with;
- formulation of the safety, reliability, availability, and maintainability criteria to be adopted for the novel technology.

The information is used to define specifications for designing, manufacturing, and installing the new technology. Similarly, the maintenance schedule is determined from a lifecycle perspective.

A certificate, class notation, or equivalent document is issued to declare that novel technology is fit for service on the TQ basis as concluded from the TQP. The required supporting documentation must be included to confirm the fitness-for-service concept:

- system specifications, drawings, technical reports, and design calculations;
- relevant rules, regulations, and standards;
- review requirements for construction, installation, and commissioning;

- operational instructions in regular and emergency situations;
- required maintenance.

Crew training and personnel certification requirements may be included in the TQP documentation. For detailed information, refer to RINA guidelines (GUI16) *"Guide for Technology Qualification Processes"* [4] and IMO MSC/Circ. 1002 [5] and MSC.1/Circ.1212[6] regarding alternative design and arrangements for fire safety and SOLAS.

2.2 AiP of the PALS System

The PALS involves the injection of air bubbles below a vessel's hull to reduce the drag friction between the hull and water. This reduction in resistance potentially leads to improved fuel efficiency and reduced greenhouse gas emissions (GHG). Its function is straightforward, leveraging basic fluid dynamics principles to achieve its goals. The difference between a classic air lubrication system and the PALS present in the RETROFIT55 project is the absence of the compressor and the use of the venturi principle.

ALS technology has been used for several decades and, as a result, is perfectly incorporated into on-board systems and operationally known in various marine applications. Therefore, classification societies have standardised the requirements for this system to prevent any safety issues. Its prolonged presence on the market underlines its reliability and reflects the vast knowledge that industry professionals have accumulated regarding its performance and safety.

As shown before, novel technologies inherently introduce new variables and uncertainties into the operational environment. Therefore, they necessitate approval in principle to ensure comprehensive identification and management of all potential risks. This process may require detailed risk assessments, pilot testing, and phased implementation. The associated operational risks are well understood and managed through existing safety protocols. Air lubrication is not considered an essential ship service, meaning the ship's safety is not compromised in case of system failure or non-availability.

In this context, conducting a risk assessment or an alternative design methodology was considered unnecessary. Although innovative, the innovation simplifies the system by eliminating the compressor, and the existing provisions of Class rules can address the remaining passive components. The classification societies have standardized the requirements for this system, specifically when it comes to RINA Rules it is examined in [7]. Therefore, the existing provisions of Class rules can address the remaining passive components, and the system's compliance with these standards ensures its operational feasibility and safety

According to RINA Rules [7], the air lubrication system is to be approved based on various documents. These documents should provide evidence that the system complies with stability, machinery and electrical installation requirements, as well as any other safety issues consequential to its integration in the ship. The documents should also outline the tests, the inspections and the commissioning procedure once the system is installed on board. Operational instructions in normal and emergency conditions and maintenance requirements may supplement the basic information needed for compliance.

Alternative arrangements, designs, and technologies that are not explicitly mentioned or do not comply with the following requirements may be considered on an individual basis, subject to a thorough risk assessment.

2.3 Documentation to be Submitted for Class Notation

Unless specified otherwise, these documents are intended for PALS. The list provided is to guide what information is needed, rather than listing specific titles. Society may request additional documents if the design is unusual or for evaluating systems, equipment, or components.

The following documents are required for informational purposes only:

- general arrangement and detail specification.

The following documents need to be submitted for approval:

- air distributors structure drawings, including connections to the ship structure;
- ship electrical load balance;
- single line diagram and circuit booklet;
- detailed diagram of the motor starters;
- valve control system diagram;
- piping system schematic diagram including valves and piping material specifications;
- stability information (in case of retrofitting, e.g. additional weight and relevant position);
- detail design of air distributors;
- detail design of air receivers.

2.3.1 Design Requirements

This section outlines the requirements for designing, installing, and testing air lubrication systems on ships. It covers hull, stability, machinery, ventilation, piping, air compressors, power and electrical systems, control, monitoring, alarms, and safety systems. These requirements apply to technologies such as air bubble, air layer, and air cavity methods, which reduce skin friction resistance using air bubbles.

Alternative designs and technologies may be accepted if they meet Class requirements.

A system like PALS must comply with various aspects of the ship's design, including hull, stability, machinery installation requirements, and equipment testing. The hull must be designed to withstand the harsh marine environment and provide the necessary buoyancy and structural integrity. Stability considerations ensure that the ship maintains its balance and does not capsize under various conditions, such as rough seas or cargo shifts. Machinery installation requirements involve adhering to standards for the placement and securing of engines and other mechanical components to optimize performance and safety. Equipment testing is crucial to verify that all installed systems function correctly and meet regulatory standards before the vessel can be deemed seaworthy. All this aspects are later in this document identified both for RINA and other main Classification Society.

<u>**TESTS ON-BOARD**</u>

A comprehensive testing program must be sanctioned by the relevant authorities, the Class Society, on board, and should encompass the following:

- check compliance of system and fittings with approved drawings;

- check of stability booklet (for retrofitting on existing ships);
- review of test certificates for components;
- visual inspection and tightness test of hull and watertight boundaries' penetrations;
- visual inspection of piping system and operational test of valves;
- leakage test of piping;
- measurement of insulation resistance of electric plant;
- functional tests of the whole system under working condition, including its monitoring, alarm and safety system;
- test of devices to prevent the return in safe space of atmosphere from the dangerous zone, if any.

3 Regulation Compliance and Framework of different Classification Societies

3.1 Review of existing regulations and guidelines

Following IMO guidelines [8] on the treatment of innovative energy efficiency technologies, classification societies have subsequently released further guidelines mapping existing regulations applicable to the subsystems of ALS. This section presents an overview of four sets of guidelines published by Registro Italiano Navale (RINA), American Bureau of Shipping (ABS), Lloyd's Register (LR) and Chinese Classification Society (CCS), respectively. This overview aims to identify similarities, differences and possible gaps in the documents published so far.

3.1.1 Registro Italiano Navale (RINA)

RINA has published guidelines [7] with requirements for the design, installation and testing of ALS on new and existing ships concerning the hull, stability and machinery.

Hull: In the design phase, the effect of the installation of ALS injectors on the local and global strength of the ship should be assessed. Calculations of the hull girder section modulus, local stress concentration due to openings and fatigue checks are to be performed. For the ALS installation, building materials as well as the workmanship must comply with the existing regulations applicable to hull structures.

Stability: The intact stability of the vessel is subject to verification due to the additional weight (although minimal and with a low centre of gravity) of ALS systems.

Machinery: This section includes requirements for ventilation, piping, air compressor and receivers, main power and electrical systems, control, monitoring alarm and safety systems. The piping network and valve installation design must comply with existing regulations. Furthermore, it is noted that non-return valves shall be placed above the double deck, and reinforcement of the piping between the hull and non-return valves is required. Similar requirements are to be met for air receivers. The air supply of the ALS should be independent of the starting and control air supply and reserve. The system's electrical components are to be designed and constructed according to requirements. Automatic control, alarm, and safety functions ensure the operation of ALS with the preset parameters for different operation conditions. Lastly, installing any machinery or equipment should allow convenient access for maintenance and operation.

3.1.2 American Bureau of Shipping (ABS)

In 2018, ABS published the Guide for Air Lubrication System Installation [9]. The guide presents recommendations for fitting ALS in the existing structure and requirements for the assembly of ALS. In the event of retrofitting, concerns are raised regarding the hull strength and the ship's stability. The regulations regarding the ALS system refer to the piping system, air compressors, air reservoirs, main power and electrical system. A more detailed review of each aspect is presented below.

General: The ALS shall not be fitted in front of the collision bulkheads. Its position should be clear from other equipment, and its design should allow convenient maintenance and repair access. Air ventilation should be sufficient for the operation of ALS machinery. SOLAS requirements apply to the structural and fire requirements.

Hull modification: Since openings are created on the hull's surface, requirements are raised concerning calculating the hull girder section modulus. Local stress concentration due to the openings must be assessed to meet the necessary standards. The shell valve design shall also meet the corresponding requirements.

Stability: The retrofitting process of the ALS system raises requirements concerning the intact and damage stability, which might be affected by the additional weight and the change of the lightship value. Therefore, the initial stability calculations and the position of the centre of gravity should be revised. Additionally, necessary steps should be taken to review the load line and stability software.

Piping and Machinery: Piping appraisal includes the details of the pipes (diameter, size and schedule), joints, valves and shell valves. Design and maximum allowable pressure, design temperature and material specifications will be reviewed according to the existing requirements. Air dispenser units must be designed with non-return valves to prevent seawater ingress and prevent progressive flooding. Additional pneumatic equipment and air reservoirs shall comply with the existing regulations. The addition of ALS shall not compromise the starting air supply. Certification shall be provided, which ensures that the discharged air (or air-water mixture) is oil-free.

Main Power and Electrical System: Electrical system details such as cable types, size, capacity, and motor circuit are to be submitted. The electrical load analysis report is also to be submitted for review. Basic ALS parameters are to be controlled and monitored to ensure the operation remains within the preset of different operation conditions. The parameters for ALS operation shall be provided locally and, if applicable, remotely: a) Air pump/compressor operational status, b) Status of any Air Lubrication System valves, c) Air reservoir pressure indicator and d) Status of any Air Lubrication system alarms, shutdowns and emergency stop. The safety system is designed to limit the consequences of potential failures.

3.1.3 Lloyd's Register (LR)

A similar framework has been developed by LR [10] that provides guidelines for integrating ALS. The guidelines consist of three parts: (a) the ship's structure, (b) the piping and machinery equipment, and (c) the electrical and control systems.

Ship's Structure: The size and location of the Air Delivery Unit (ADU), may directly affect the global and local hull strength. The assessment of global strength should be revised, if applicable, where the original assessment by direct calculation, structural and fatigue design assessments have been meaningfully deviated from.. The detailed design should appreciate the limited access, fit up requirements, weld sequencing and weld procedures. Furthermore, the guide raises concerns about slamming in adverse weather conditions and the rudder design concerning the maximum ship speed.

Piping and Machinery: Piping system components such as material, schedule, valves and pressure reliefs shall all be designed and documented based on existing regulations. Valves should be appropriately selected based on accessibility, closing arrangement and control. The piping network should not introduce any additional hazards, and the side shell valves should be installed as close as possible to the side shell. Furthermore, consideration should be made for working temperature and pressure, thermal expansion and corrosion, and protection against hazardous events that can harm the ship's personnel.

Electrical and control: The electrical power balance shall not be affected by the integration of the ALS system. Similar requirements for an air blower should be considered. The power system needs to be controlled both locally and remotely. Finally, concerning cable penetration, they should consider structure and space designation.

3.1.4 China Classification Society (CCS)

CCS has published guidelines [11] providing the technical requirements for the system design, air supply devices, piping systems, air layer/ bubble generators, air escape protector, power supply and electrical systems, and control and monitoring systems. The guidelines aim to ensure that the system will maintain continuous normal operation under the design environmental conditions, its operation will not interfere with other equipment, and the injection fluid will be oil-free. The main points of the system are outlined below.

Strength and stability: In the case of retrofitting, the influence of ALS in the longitudinal strength is to be evaluated. Hull girder sectional properties are to meet CCS rules for Classification of Sea-Going Steel Ships for openings. The intact stability and damage stability of ships should be revised according to the relevant requirements. The effect of the ALS on the lightship weight, ship's centre of gravity and stability information are to be re-evaluated.

Machinery: Air supply devices, air compressors and blowers, air reservoirs, and safety and relief valves fall into this category. The ventilation of the air supply device should be sufficient, considering its air consumption and cooling requirements. Dedicated air compressors and reservoirs shall be used without compromising the usage of other systems. Furthermore, a pressure gauge and safety valve are to be fitted to air compressors.

Piping: All piping systems shall meet the general requirements of CCS rules. The flow on the piping system should be monitored and controlled. Non-return valves shall be fitted to prevent sea water ingress.

Air Injection System: The watertight structural members of ALS are to meet the requirements for shell plating. Local stress concentration induced by the openings is to be evaluated according to the actual conditions. Furthermore, if a longitudinal air escape protector is used, it should not be fitted directly on the shell plating; instead, backing boards are to be fitted.

Electrical and control: The electrical installation of ALS should meet the requirements, as listed out in the CCS Guidelines. An electrical load analysis should be carried out and submitted for analysis. The monitoring system's operation of ALS should be displayed locally and, if applicable, remotely. The following parameters should be shown: (1) air compressor/blower operational status, (2) opening and closing of air supply valves or opening extent, (3) air flow, (4) air reservoir pressure, (5) air supply pressure before the air layer/bubble generation, (6) system alarms, and (7) system shutdown and emergency stop.

3.2 Files to be prepared/submitted for Class Approval

The following Table 1 compares the submission documents required as a minimum by each classification society.

Table 1: The required documents are to be submitted for ALS approval.

Purpose of Appraisal	Submission Document	RINA	ABS	LR	CCS
Structural	Vessel-specific general arrangement of ALS	☑	☑	☑	☑

Structural	Hull penetration details with location indicated on structural drawing. (e.g. shell expansion)	☑	☑	☑	☐
Structural	Welding details of ALS injectors	☐	☑	☐	☐
Structural	Detail design drawing of ALS injectors	☑	☑	☑	☑
Structural	Detail design drawing of ALS receivers (air or water)	☑	☐	☐	☐
Structural	Structural plan of air escape protector (if any)	☐	☐	☐	☑
Structural	Information related to any limitations of the vessel (service restrictions or other)	☐	☐	☑	☐
Structural	Docking plan showing position of ADUs	☐	☐	☑	☐
Structural	Material specification	☐	☑	☐	☐
Structural	Stability Information	☑	☐	☐	☐
Piping	Arrangement of piping system including any new or modified systems	☑	☑	☑	☑
Machinery	Arrangements of ALS machinery and equipment	☐	☑	☑	☑
Machinery	Miscellaneous machinery diagrams. Drawing and details of actuating mechanism (piped design and working pressure and temperature, inner and outer diameters, thickness, and material)	☐	☑	☑	☐
Machinery	Ventilation diagrams for air lubrication system machinery space	☐	☑	☐	☐
Machinery	Manufacturer’s certificate for air compressor attesting that the released air is oil-free	☐	☑	☐	☐
Electrical	Electrical load analysis	☑	☑	☐	☑
Electrical	Interfaces with ship’s control, alarms, and safety system	☐	☐	☑	☐
Electrical	Cable diagram for power system	☑	☑	☑	☑
Electrical	Miscellaneous electrical diagrams, including **(a)** circuits Ventilation system, **(b)** cable type, sectional area of conductor, current rating of electrical system, insulation type, **(c)** circuits of the motor and motor protection (if applicable) **(d)** interfaces with ship's electrical systems; (**e**) interfaces with ship's electrical systems	☑	☑	☑	☑
Electrical	Description of operation with explanatory diagrams	☐	☐	☑	☐
Electrical	Emergency shutdown arrangement, including list of alerts, alarms and actions required by the Operators.	☐	☑	☑	☑

3.3 Proposed framework

Based on the existing regulation framework in the following paragraphs, a revised and harmonised set of provisions is proposed based on current experience and state of play in ALS design.

3.3.1 Hull

Strength: The openings on the hull surface can affect the vessel's longitudinal strength. In the case of ship retrofitting, the calculation of hull girder sectional properties should be revised. The local strength of the hull might also be affected. Assessment of stress concentration due to openings shall be evaluated according to the actual conditions to meet requirements for strength and fatigue. If ALS includes water intakes at the bow, they shall be designed to fit the specifications of a sea chest.

Stability: Additional weights of the ALS may be important and subsequently affect the intact stability of the ship. ALS should comply with the relevant existing requirements. Furthermore, the hydrostatic characteristics of the vessel may also be affected. Based on the change of the lightship condition and longitudinal centre of gravity, the stability manual and loading instrument should be re-evaluated.

Marine Growth: Considerations shall be made to prevent marine growth within ALS cavities and in the openings on the hull surface. An appropriate blowout mechanism shall be incorporated to ensure the efficient cleaning of the ALS pipes. Furthermore, the pipe design requirements should account for the potential pressure increase inside the piping network due to the marine growth.

3.3.2 Machinery

Air Inlets: Air inlet ports above the deck used to supply air to the system are to comply with RINA Rules [12].

Air Compressors and Reservoirs**:** Details of the pneumatic equipment used shall be submitted for review. Appropriate considerations shall be made for the ventilation, including air consumption requirements and the effective cooling of the mechanical equipment. ALS installation shall not compromise the starting of the propulsion and auxiliary systems. Dedicated air compressors and reservoirs shall be used, or alternative considerations shall not affect the compressed air supply to start the main engines.

Fire and Safety**:** Personnel should be protected against any hazards related to high pressure and temperature. When ALS components are placed in high-risk areas, necessary fire protection requirements should also be made. Particular care and planning are required when ALS installation is carried out in vessels in Hazardous Areas (i.e. Tankers, LNG Carriers, etc.)

Arrangement**:** The General arrangement of the system should clearly show the space it occupies and ensure adequate clearance from other mechanical equipment and clear passage for crew passage and evacuation.

3.3.3 Piping

Pipe specifications**:** The piping network of the ALS is subject to the design requirements described in RINA Rules [12]. The piping diagram should include information such as diameter, size, schedule, design pressure, maximum allowable pressure, and temperature.

Valves**:** Valves used for ALS are subject to RINA Rules [12] requirements. Valve accessibility should be ensured. Pressure gauges and relief valves shall also be fitted to monitor and control the flow inside the piping system. Remote Controlled screw down non-return valves shall be equipped to any openings below the water line to prevent undesirable water ingress. Such valves must have Class Society Type Approval certificates, which have requirements similar to those for overboard Valves.

3.3.4 Electrical

Electrical: The power integration of the ALS into the ship's grid should not adversely affect the ship's power consumption. Regulations apply to the electrical system and electrical equipment of ALS. The submission should include design details such as construction standards, cable type, size and capacity, and the motor circuit and protection information. The electrical system shall be designed in such a way as to minimise the risk of failure. This should be included in the electrical load analysis.

The provided ALS panels should comply with Arc Flash Hazard requirements, while any additional breakers installed shall be checked for short circuit current and discrimination.

Control: ALS should be controlled both locally and remotely. A safety system is to be designed to limit the consequences of a potential malfunction. In the event of failure, an alarm is to be activated.

Furthermore, the following operational parameters of ALS are to be displayed locally and, if applicable, in the remote station:

1. Air compressor operational status
2. Status of Air Lubrication Valves
3. Air/Water flow
4. Air reservoir pressure
5. System alarms status
6. System shutdown and emergency stop.

4 Closing remarks

The preceding sections of this deliverable have meticulously reviewed the Standards, Rules, and Regulations pertinent to marine systems. Furthermore, an overview of the certifications that Classification Societies may issue has been provided to enhance the commercial impact of the project outcomes and to foster further innovation. This approach aims to create value for both industry stakeholders and regulatory bodies.

PALS technology is based on the venturi principle, which distinguishes it from traditional systems ALS. Current safety protocols permit PALS implementation without any need of additional risk assessments, which are generally required for novel technologies, this is because the PALS system is deemed not a new technology. Compliance with RINA and other classification societies' standards ensures its operational feasibility and safety. Although there are differences between the features of each ALS, the equipment used is similar, facilitating the definition of a common regulatory framework. Furthermore, since the components of ALS are essentially known in the shipbuilding industry, the framework is based on existing rules without the need to develop new provisions.

In this deliverable, the importance of a comprehensive regulatory framework for the successful implementation of PALS was evaluated and emphasised to facilitate the standardisation of the approval process, exploit the potential of such technologies, enhance hydrodynamic efficiency and reduce hull friction without compromising safety. It is expected that continuous monitoring and periodic reviews of the regulatory framework will be necessary to reflect continuous technological advancements and emerging solutions in the maritime sector.

This deliverable provides guidance on the as-is regulatory framework and its application, useful from the concept design, encompassing the engineering phases, testing, validation and integration onboard of marine equipment for the benefit of manufacturers, shipyards and shipowners. Adopting PALS could significantly improve fuel efficiency and performance in the maritime industry, promoting more sustainable shipping. Using the venturi principle, PALS modernises operations and saves energy. Compliance with Classification Society standards ensures safety and reliability. As environmental targets evolve, systems like PALS will be essential for greener and more efficient operations.

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