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DRONE OPERATION FOR MARINE AIDS TO NAVIGATION AND VTS INFRASTRUCTURE MANAGEMENT

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1. INTRODUCTION

During the inspection of Marine Aids to Navigation (AtoN), such as lighthouses and Vessel Traffic Services (VTS)-related infrastructure, on-site inspectors may encounter challenges in directly accessing the site. These limitations can expose personnel to safety risks and restrict their ability to thoroughly assess facility conditions.

To address these challenges, AtoN authorities have introduced drones to support inspections and related tasks on high-rise structures such as lighthouses, beacons, and other difficult-to-reach objects or hazards. By using drones, it becomes possible to capture aerial imagery and video of AtoN facilities that are otherwise hard to access visually.

Drones equipped with cameras, Light Detection and Ranging (LiDAR), and Real-Time Kinematic (RTK) modules can collect high-resolution imagery and precise geo-referenced data, enabling a more accurate understanding of an AtoN's condition, including positioning, structural damage, and component failures.

Drone inspections can be particularly effective during adverse sea and weather conditions, such as high seas, when access is only possible from the sea, or when the terrain or location on land presents vehicle access difficulties. This approach helps overcome personnel access issues at certain sites, thereby enhancing inspection coverage and supporting more effective and efficient maintenance. However, it should also be acknowledged that adverse weather conditions at sea may impact drone operations.

In addition to improving staff safety and reducing operational costs, the use of drones contributes to sustainability by lowering fuel consumption and emissions through reduced reliance on vessels. Drones also facilitate timely data acquisition and faster detection of anomalies.

Furthermore, drones can support the preservation of heritage structures such as lighthouses by identifying early signs of deterioration, drainage blockage, animal infestation, or other forms of damage, thereby contributing to the achievement of the United Nations Sustainable Development Goals (SDGs) 9, 11.4, and 13.

For the purpose of this guideline, drones refer specifically to Unmanned Aerial Vehicles (UAVs). It is anticipated that in the future, surface and submersible drones may be used to support AtoN inspection and management, and this guideline will be updated as the technology matures.

The following Guideline should be read in conjunction with Recommendation R1018 Responsible design, operation and maintenance in the provision of marine aids to navigation.

2. SCOPE

Within this guideline, the term 'Drone' refers to any remotely controlled Unmanned Aerial Vehicle (UAV) used in the management of AtoN. Drone operations may include, but are not limited to:

- AtoN installation
 - Drones can be used to perform an on-site LiDAR site survey to provide the parameters for the engineering design of the proposed AtoN.
- AtoN improvement and review
 - Data from drone operations can assist in performance analysis and in post-incident reviews.
- AtoN inspection
 - Drones may support inspection tasks in areas difficult to access by vessel or in poor sea conditions.
- AtoN maintenance
 - Drones may enable periodic condition reviews and support numerical modelling of AtoN for early issue detection.
- VTS infrastructure inspection and monitoring



Drones may be used to carry out inspections of structures that directly support VTS, such as shore- or offshore-based radio and radar sites. This is particularly useful for locations that present access challenges, such as tower structures.

It should be noted that this guideline only covers “Line of Sight” (LOS) drone operations. Any drone activity involving “Beyond Visual Line of Sight” (BVLOS) requires a separate set of rules and associated guidance. BVLOS operations involve flying a drone or other unmanned aircraft without the pilot maintaining direct, unaided visual contact with the aircraft, instead relying on technology to monitor and control it. This mode of operation enables drones to fly greater distances for applications such as long-distance deliveries and infrastructure inspections. Because BVLOS operations introduce increased risks due to the pilot’s inability to see the drone directly, they are subject to stringent regulation by aviation authorities and require specific operational authorizations or waivers before being conducted.

2.1. DESIGNATION OF ROLES

The roles involved in drone operations are as follows:

- Competent authority: An authority made responsible, in whole or in part, by the government for the safety and efficiency of Marine Aids to Navigation (AtoN) services.
- Drone operator: The nominated authority within the organisation for drone operations, administration, maintenance oversight, and supervision of drone pilots
- Drone pilot: The person responsible for flight planning, pre-operation checks, and drone operation
- Drone maintenance technician: The person responsible for routine drone maintenance
- National regulator: The relevant national authority

In some circumstances, one person or organisation may hold multiple roles.

3. APPLICATION SCENARIOS

This chapter provides examples of practical applications of drones in the management of AtoN. While not exhaustive, the scenarios below illustrate how drones can enhance inspection, deployment and monitoring tasks across a range of operational contexts.

3.1. ROUTINE VISUAL INSPECTION

Drones may be used to support routine visual inspection of AtoN. Typical activities include position verification, evaluation of external condition and structure, observation of light characteristics, and photographic documentation. The use of drones enables improved access to elevated or remote structures and can supplement existing inspection practices.

3.2. ATON MALFUNCTION INSPECTION

When a fault alarm or anomaly is reported by an AtoN monitoring system, drones can be deployed for rapid on-site assessment. Drones allow for remote visual verification, capture of site conditions, and may support initial fault classification. This reduces response time and improves situational awareness before dispatching maintenance personnel.



3.3. SUPPORT FOR ATON DEPLOYMENT

Drones can be used during planning and deployment of new AtoN structures. They support site assessment, terrain surveying, and photographic mapping. This is particularly valuable in areas with limited access, such as remote islands, rocky shorelines, or hazardous environments where conventional methods may be time-consuming or pose safety risks.

3.4. VTS INFRASTRUCTURE INSPECTION AND MONITORING

Drones may be used to inspect VTS sensors and associated infrastructure, including radar, radio, and other systems that support VTS operations.

3.5. OTHER APPLICATION SCENARIOS

Additional applications may be considered based on operational needs and available drone capabilities. These may include, but are not limited to:

- Detection and monitoring of radio signals or interference
- Assessment of lighthouse luminous range and visibility
- Performance checks of radar beacons (Racon)
- Remote activation or control of AtoN equipment
- Aerial documentation for heritage, public outreach, or training purposes
- Assistance in incident management, where applicable

The competent authority or drone operator is encouraged to assess the suitability of drones for these or other operational tasks, in line with applicable safety, technical, and regulatory requirements.

4. FINANCIAL AND OPERATIONAL CONSIDERATIONS

Before introducing drones into AtoN operations, the competent authority should consider the associated financial and operational implications. A structured assessment of cost elements, resource needs, and long-term benefits will support sustainable implementation and service continuity.

4.1. INFRASTRUCTURE AND PERSONNEL REQUIREMENTS

Initial and ongoing costs may be influenced by:

- Establishment of drone take-off and landing zones
- Ground control stations and supporting communication equipment
- Certification and training requirements for drone operators and drone pilots

4.2. ENVIRONMENTAL AND OPERATIONAL FACTORS

Cost-effectiveness and feasibility may depend on:

- Size, location, and complexity of the operational area

- Frequency and duration of drone deployment cycles
- Availability of existing infrastructure and support systems
- Local environmental conditions such as wind exposure, terrain, and restricted airspace

4.3. FINANCIAL INPUTS AND ANTICIPATED BENEFITS

The following elements should be considered in a cost-benefit analysis:

- Procurement costs and expected service life of drones
- Costs for spare parts, battery systems, and insurance
- Maintenance and operational expenditures
- Costs associated with software, data systems, and technical integration
- Training and certification expenses
- Potential cost savings through reduced vessel operation and manpower requirements
- Additional value in terms of improved safety, enhanced accessibility, and more consistent data acquisition

The competent authority is encouraged to conduct a cost-benefit analysis tailored to its operational needs, budgetary environment, and regulatory framework.

5. PURCHASE AND REGISTRATION

The drone operator should evaluate operational efficiency and suitability when purchasing drones. Factors such as environmental conditions and mission requirements should be considered, including the need for waterproof or weather-resistant drones.

Each drone purchase should be reported to the responsible authority and registered in accordance with national legislation. The drone operator should also ensure that appropriate insurance coverage is obtained, as per national legislation or applicable guidelines.

6. DRONE OPERATIONS MANUAL

An operations manual is a vital document for ensuring the safe, compliant, and efficient operation of a drone. It serves as a comprehensive management tool that details all operational processes, regulatory requirements, and roles and responsibilities. The manual demonstrates the organisations' commitment to safety, legal compliance, and best practices by providing clear procedures for routine operations as well as contingency and emergency protocols. In preparing this manual, operators should also acknowledge that local registration and regulatory requirements may vary significantly and must be incorporated accordingly.

6.1. REGULATORY COMPLIANCE

The operator should commit to adhering to all relevant national, regional, and local regulations, including local registration requirements governing drone operations. Emphasis is placed on safety, standardized operational procedures, and fostering a "just culture" where personnel can report safety concerns without fear of reprisal.

6.1.1. SECURITY AND PRIVACY STATEMENT

The operator should ensure the protection of personal and operational data in compliance with applicable national and regional legislation. Systems and protocols must be in place to prevent unauthorized access, misuse,



or loss of sensitive information. Where appropriate, references to local data protection standards (e.g., General Data Protection Regulation (GDPR) in the EU, or equivalent national laws) may be included in the organisation's internal procedures.

6.1.2. ENVIRONMENTAL STATEMENT

The operator should commit to minimizing environmental impact through sustainable practices. This includes reducing noise, emissions, and energy consumption during operations to promote eco-friendly drone use.

6.2. ORGANISATIONAL STRUCTURE AND DOCUMENT CONTROL

6.2.1. OPERATIONAL ORGANISATION

Operational organisation provides an overview of the organisational structure, detailing the roles and responsibilities of key personnel such as operators and maintenance crew. An organisational chart may be included to clearly visualize the team hierarchy.

6.2.2. DOCUMENT CONTROL

Document control outlines the procedures for managing all documentation related to drone operations.

6.2.2.1. Revision Management

A clear process should be in place for updating the operations manual. All changes should be reviewed and approved by the competent authority before implementation. Updates must be communicated to all relevant personnel to ensure they are working with the most current version.

6.2.2.2. Document Distribution and Retention

Documents should be distributed digitally or in hard copy to ensure that all personnel have access to the latest information. Important records such as flight logs, personnel qualifications, safety procedures, and maintenance records should be retained for a specific period to comply with national and local regulatory requirements.

6.3. OPERATIONAL PROCEDURES

6.3.1. OPERATIONAL PLANNING

Comprehensive planning should incorporate up-to-date resources such as maps, AtoN data, and weather reports to ensure safe drone operations. The planning process should verify compliance with geographical zones and airspace restrictions and include coordination with Air Traffic Control (ATC) and VTS centres when operating near controlled airspace or within a VTS area.

6.3.2. PRE-FLIGHT AND POST-FLIGHT INSPECTIONS

Thorough inspections before and after each flight are essential to confirm that the drone is airworthy. Standardized checklists should be used, and all findings and corrective actions must be documented.

6.3.3. EMERGENCY AND CONTINGENCY PROCEDURES

Emergency and contingency procedures establish protocols to manage unexpected situations, such as adverse weather conditions, equipment malfunctions, or airspace intrusions. These procedures should include steps for loss of communication links and other system failures, ensuring that pilots are trained and ready to mitigate risks swiftly.

6.4. OPERATIONAL LIMITATIONS

This section details the limitations based on the drone manufacturer's specifications and ensures operations remain safe and compliant.



6.4.1. ENVIRONMENTAL CONDITIONS

- Light conditions: Drone operations should be conducted during daylight hours or under conditions specified by the manufacturer to ensure appropriate visibility for safe operation.
- Wind and weather: Operations should be carried out only when wind speeds and weather conditions remain within the acceptable limits defined by the manufacturer. Adverse conditions such as heavy rain, snow, or hail should be avoided as they may compromise safety.
- Temperature range: The drone should operate within the temperature parameters recommended by the manufacturer to minimize the risk of equipment malfunction.

6.4.2. TECHNICAL LIMITATIONS

- Maximum take-off weight (MTOW): The drone should remain within the maximum take-off weight defined by the manufacturer to maintain flight stability and control.
- Flight speed and altitude: The operating speed and altitude of the drone should not exceed the maximum limits specified by the manufacturer. In general, flight altitude should be limited to 120 metres above ground level unless otherwise authorized.
- Flight angles: The drone should maintain pitch and roll angles within safe operating thresholds defined by the manufacturer to ensure flight stability.

6.4.3. FLIGHT AREAS AND RESTRICTIONS

- Controlled areas: Drone operations should be carried out in controlled areas that are clearly marked and secured from unauthorized access. The operator should ensure that the operational area remains secure throughout the duration of the activity.
- Geographical zones: Drone operations should comply with any national or local restrictions related to geographical zones, including no-fly zones or airspace constraints. Required clearance should be obtained before flight.
- Critical infrastructure considerations: In certain instances, VTS sensors may form part of the critical national infrastructure. In such cases, any drone operations conducted in the vicinity of these sites may require additional approvals from the appropriate government agency prior to commencement.

6.4.4. AUTOMATED AND MANUAL CONTROL

Automated flight systems such as geofencing and return-to-home functions should be configured to support safe and compliant drone operation. Manual override capability should be available at all times to allow the drone pilot to take direct control of the drone when necessary.

6.4.5. PAYLOAD AND BATTERY

- Payload limits: The total payload carried by the drone should be within the manufacturer's recommended limit to maintain performance and flight efficiency.
- Battery management: Battery levels should be continuously monitored to ensure adequate power for the entire flight, including return and landing phases. Batteries should be charged, stored, and managed according to the manufacturer's recommendations to maintain performance and safety.

6.4.6. MANUFACTURER COMPLIANCE

All operations should conform to the manufacturer's operational guidelines. Operators should conduct regular reviews of manufacturer updates to remain informed of any changes in limitations or procedures.



7. PERSONNEL REQUIREMENTS

Personnel involved in drone operations should meet appropriate qualification, training, and health standards to ensure safe and effective drone use. All training and competency requirements should comply with applicable national regulations. The drone operator should ensure that all personnel are trained, certified (where required), and competent to carry out their assigned responsibilities.

7.1. QUALIFICATION AND ROLES

- Drone operators: The drone operator should hold suitable qualifications for overseeing mission planning, risk mitigation, and overall safety of drone operations. This includes knowledge of airspace regulations, flight planning procedures, and coordination with the competent authority and national regulator as required.
- Drone pilot: The drone pilot should possess a valid remote pilot certification or equivalent in accordance with national or local regulations.
- Drone maintenance technician: Maintenance personnel should have the appropriate technical knowledge and experience to carry out drone maintenance tasks, including inspections, repairs, and system checks to ensure airworthiness.
- Ground crew: Ground support personnel should be trained to perform their designated roles, which may include assisting with launch and recovery, monitoring communications, and maintaining ground safety procedures.

7.2. TRAINING AND COMPETENCY

Training and competency requirements should be established to ensure that all personnel involved in drone operations possess the necessary knowledge, skills, and proficiency appropriate to their roles.

7.2.1. DRONE OPERATOR TRAINING

Drone operators should be trained in:

- Mission planning and risk mitigation
- Airspace regulations and coordination procedures
- Oversight of pilot performance and safety standards

7.2.2. DRONE PILOT TRAINING

The drone operator should ensure that drone pilots receive appropriate training to achieve and maintain certification requirements. Training should cover:

- Drone operation and handling
- Safe and efficient operation planning
- Risk assessment for specific drone activities
- Maintenance of drones and equipment
- Updates on national legislation and regulatory compliance
- Processing, analysis, and storage of data acquired



7.2.3. DRONE MAINTENANCE TECHNICIAN AND GROUND CREW TRAINING

Personnel involved in maintenance or ground support should be trained to carry out inspections, communication procedures, safety protocols, and equipment handling relevant to their roles.

7.2.4. CREW RESOURCE MANAGEMENT

Crew resource management (CRM) training should be provided to promote effective communication and coordination among drone operation personnel. This is especially important for missions involving multiple crew members or complex operational environments.

8. MANAGEMENT OF DATA ACQUIRED

8.1. DATA STORAGE & ACCESS

Acquired data should be managed and stored in an appropriate manner, in accordance with relevant national regulations. The competent authority should ensure that data is accessible for future use by internal or external stakeholders, such as Port Authorities or environmental agencies. Consideration should be given to data privacy requirements, storage formats, and the anticipated volume of data.

8.2. DATA PROTECTION

The protection of data acquired through drone operations, including metadata such as time and location, should be carried out in compliance with applicable national regulations. Cybersecurity measures should be adopted to ensure the integrity, confidentiality, and availability of the data.

9. MAINTENANCE OF DRONE EQUIPMENT

9.1. MAINTENANCE OBLIGATION

The drone operator should establish a structured maintenance programme aligned with the manufacturer's recommendations applicable national regulations, and organisational procedures. The drone pilot should follow established maintenance protocols to ensure safe and reliable operation.

Maintenance should be conducted to maintain airworthiness, comply with national regulatory requirements, minimise operational risks, and prevent failures during operations.

9.2. TYPES OF MAINTENANCE

9.2.1. PREVENTIVE MAINTENANCE

Preventive maintenance ensures drones remain in optimal working condition and prevents unexpected failures. The following measures should be taken:

- Routine pre-flight and post-flight inspections to detect visible issues.
- Scheduled maintenance activities in accordance with the manufacturer's guidance and organisational policies.
- Event-driven inspections following maintenance, repairs, or component replacements.

- Specialized inspections conducted by external professionals when internal capabilities are not sufficient.

Where applicable, the competent authority or drone operator may adopt a structured inspection cycle, including comprehensive reviews on a semi-annual or annual basis. The drone operator is encouraged to refer to the drone manufacturer's maintenance instructions and relevant national standards for detailed requirements.

9.2.2. CORRECTIVE MAINTENANCE

Corrective maintenance refers to actions taken in response to failures, damage, or operational malfunctions. If a drone experiences damage or system failure:

In the event of a failure, all incidents should be documented and reported to the drone operator, competent authority, and national regulator in accordance with national regulations. Repairs and replacements should follow manufacturer guidelines to ensure compliance with operational standards. Additionally, risk mitigation strategies should be implemented to prevent repeated failures and enhance overall reliability.

9.3. KEY MAINTENANCE COMPONENTS

9.3.1. PROPELLER AND BATTERY MAINTENANCE

The drone operator, under the oversight of the competent authority, should establish contingency procedures to minimize operational risk and support the safe recovery of the drone and its components in the event of an incident.

- Propeller maintenance: Propellers should be regularly inspected for signs of wear, imbalance, or damage. Damaged components should be replaced promptly to ensure flight safety.
- Battery maintenance: Batteries should be inspected frequently for signs of deterioration, including reduced capacity or physical swelling. Charging and storage should follow manufacturer recommendations. Batteries identified as degraded or unsafe should be withdrawn from service.

9.3.2. SOFTWARE AND SYSTEM UPDATES

Software updates provided by the manufacturer should be implemented in a controlled manner. Following each update, verification procedures such as test flights should be conducted to ensure all systems function as intended. Any identified issues should be resolved before the drone is returned to operational use.

9.4. REPORTING AND DOCUMENTATION

To ensure effective maintenance management, records should be systematically maintained to document all inspections, repairs, and component replacements. These records serve as a reference for operational continuity and help identify trends in equipment performance over time.

When failures, damage, or system malfunctions occur, detailed incident reports should be submitted in accordance with established reporting procedures. This ensures that corrective actions are properly documented and that operational risks are mitigated.

Compliance with regulatory requirements is a key aspect of drone operations. All maintenance-related documentation, including inspection logs, incident reports, and service records, should be retained in alignment with national standards and organisational policies. Maintaining accurate records supports accountability and enhances operational oversight.

9.5. DISPOSAL

When a drone or its components are deemed no longer serviceable due to age, damage, or loss, the issue should be reported to the drone operator in line with internal reporting procedures.

Disposal should be carried out in an ethical and environmentally responsible manner, in compliance with national regulations and sustainability policies set by the competent authority or relevant governing body.



10. ABBREVIATIONS

ATC	Air Traffic Control
BVLOS	Beyond Visual Line of Sight
CRM	Crew Resource Management
GDPR	General Data Protection Regulation
LiDAR	Light Detection and Ranging
LOS	Line of Sight
MTOW	Maximum Take-off Weight
RTK	Real-Time Kinematic
SDGs	Sustainable Development Goals
UAV	Unmanned Aerial Vehicle
VTS	Vessel Traffic Services

11. FURTHER READING

- [1] International Organization for Marine Aids to Navigation (2023) Standard 1020 Marine Aids to Navigation Design and Delivery.
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