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1 INTRODUCTION

1.1 Scope

Beside and taking benefit from the technical development made during the OCEAN2020 project, this document provides recommendations for unmanned system deployment policy, recommendations for Unmanned Air Vehicle (UAV) flight safety standardisation and procedures, recommendations for situation awareness standardisation, recommendations for unmanned interoperability standardisation, policy recommendations for unmanned system integration.

In addition to partners' existing knowledge, all these aspects take into account experience gathered during the OCEAN2020 development and especially during the simulated and live demonstration trials.

This document, D6.6.2, constitutes a completed and final issue of D6.6.1

1.2 Overview

As basis of this document, the 36 operational scenarios defined in scope of this project are presented. Each of them use either one or several Unmanned Systems (UxSs).

For each recommendation aspect, a methodology is detailed.

Recommendations for unmanned system deployment policy are developed along 3 axes: operational requirements (especially dealing with deployment and recovery; required support and infrastructure, communication availability), human factors (especially through UxS crew human factors), legal and ethical issues (including rules of air/sea, ethical aspect linked to the use of weapons on UxSs).

Recommendations for UAV flight safety standard and procedure are addressed first through extraction of Concepts of Operation (CONOPS) with a view on air safety. Before providing recommendations, the state of the art regarding airworthiness regulation is presented for civil and military UAV.

Recommendations for integrating UAV with Air Traffic Management (ATM) rules are presented while considering ATM differences between Europe and the USA and the associated approaches for the safe insertion for small and large platforms. Support to development of an EUDAAS is presented. Recommendations for elaboration of European Union (EU) standards for safety deployment are addressed with two views: the need for new standards and recommendations for hazard classification/severity classification for each scenario.

Recommendations for Maritime Situational Awareness (MSA) standardisation are presented through a four step approach: summarise of state of the art in MSA, identify barriers to improved MSA (including legal aspects); added value of UxS for MSA and then recommendations (including environmental situation awareness, vehicle situation awareness and autonomous anti-collision situation awareness).

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Recommendations for unmanned interoperability standardization are considered through three main parts. The first deals with the data distributed by the unmanned systems in terms of structure and type. This part introduces also the relevant existing standards (STANAGs and others). The second part addresses the cooperation between Unmanned Systems (swarming). The final part introduces the Handover recommendations after exploring its main issues.

Recommendations for unmanned integration are presented after introducing a typical UxS system and verification and validation process. Additionally to generic recommendations for the Verification and Validation (V&V) process, they provide details for each UxS domain. Finally, recommendations for unmanned integration are presented with identification of suitable existing standards.

1.3 Document structure

The document structure is the following:

- OCEAN2020 operational scenarios
- Recommendations for unmanned system deployment policy,
- Recommendations for UAS flight safety standard and procedures,
- Recommendations for situation awareness standardization,
- Recommendations for unmanned interoperability standardization,
- Policy recommendations for unmanned system integration

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1.4 *Glossary*

1.4.1 Acronyms

ACO	Ant Colony Optimization
ADCP	Acoustic Doppler Current Profiler
ADS-B	Surveillance Broadcast
AIS	Automatic Identification Systems
AMC	Acceptable Means of Compliance
AOI	Area of Interest
AOO	Area of Operation
ASW	Anti-Submarine Warfare
ATC	Air Traffic Control
ATM	Air Traffic Management
AUV	Autonomous Unmanned Vehicle
BDA	Battle Damage Assessment
BVLOS	Beyond Visual Line of Sight
C2	Command and Control
CACOC	Chaotic Ant Colony Optimization to Coverage
CAS	Collision Avoidance System
CD&E	Concept Development and Experimentation
C-ESM	Communication Tools
CLF	Commander Landing Force
CNS	Communication, Navigation, Surveillance
CS	Certification Specification
CSMA	Collaborative Space-based Maritime Situational Awareness
CTD	Conductivity Temperature Dept
DAA	Detect and Avoid
DAL	Development Assurance Level

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DUO	Designated Unmanned Aerial Vehicle Operator
DVL	Doppler Velocity Log
EM	Electromagnetic Spectrum
EMI	Electromagnetic Interference
EMSA	European Maritime Safety Agency
EO	Electro-Optical
EO/IR	Electro-Optical/Infra-Red
EOS	Electro Optical Systems
ESM	Maritime Surveillance Radars, Electronic Support Measures
EU	European Union
EUDAAS	European Union Detect and Avoid System
FHA	Functional Hazard Assessment
FIAC	Fast Inshore Attack Craft
FTP	File Transfer Protocol
GEO	Geostationary Orbits
GM	Guidance Material
GMTI	Ground Moving Target Indicator
GPS	Global Positioning System
HF	High Frequency
HVU	High Value Unit
HMI	Human to Machine Interface
IED	Improvised Explosive Device
IFF	Identification Friend or Foe
IMO	International Maritime Organization
IR	Infra-Red
ISAR	Inverse Synthetic Aperture Radar
ISTAR	Intelligence Surveillance Target Acquisition & Reconnaissance
LEO	Low Earth Orbit
LL	Lost Link

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LOS	Line of Sight
LRIT	Long Range Identification and Tracking
LRAD	Long Range Acoustic Device
M&S	Modelling and Simulation
M2M	Machine-to-machine
MALE	Medium Altitude Long Endurance
MBSE	Model-Based Systems Engineering
MCDC	Multinational Capability Development Campaign
MCM	Mine Countermeasures
MCMV	Mine Countermeasure Vessels
MHV	Mine Hunting Vessels
MOD	Ministry of Defence
MOPS	Minimum Operational Performance Standards
MSA	Maritime Situational Awareness
MSR	Maritime Surveillance Radars
MUT	Manned and Unmanned Teaming
NAF	NATO Architectural Framework
NFS	Naval Firing support
NOTAM	Notices to Airmen
NRT	Near Real Time
OCEAN	Open Cooperation for European mAritime awareNess
OTH	Over the Horizon
PADR	Preparatory Action on Defence Research
PAM	Passive Acoustic Monitoring
PAR	Photo-synthetically Available Radiation
POL	Point of Load
PSSA	Preliminary System Safety Assessment
QoS	Quality of Service
R-ESM	Radar Electronic Support Measures

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RHIB	Rigid Hulled Inflatable Boat
RLOS	Radio Line-Of-Sight
RMP	Recognised Maritime Picture
ROE	Rules of Engagement
ROV	Remotely Piloted Vehicle
RTL	Round-Trip Latency
RUAS	Rotary Unmanned Aerial System
RVT	Remote Virtual Tower
S&R	Search and Rescue
SA	Situational Awareness
SAR	Synthetic Aperture Radar
SARsat	Synthetic Aperture Radar Satellite
SATCOM	Satellite Communication
SC	Special Conditions
SIGINTSat	Unclassified Signal Intelligence Satellite
SME	Subject Matter Expert
SSA	System Safety Assessment
SSM	Surface-to-Surface Missile
SSR	Secondary Surveillance Radar
TCAS	Traffic Collision Avoidance System
TCP/IP	Transmission Control Protocol/Internet Protocol
TRU	Target Report Unit
UAS	Unmanned Air System
UAV	Unmanned Air Vehicle
UAxS	Unmanned Autonomous Systems
UDP	User Datagram Protocol
USS	Unmanned Surface System
USV	Unmanned Surface Vehicle
UUV	Unmanned Underwater Vehicle

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UW	Under Water
UxV	Unmanned Vehicle
V&V	Verification and Validation
V&V	Verification and Validation
VHF	Very High Frequency
VMS	Vessel Monitoring System
VTS	Vessel Traffic Service

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1.4.2 Definitions

- *C3: Command, Control and Communications are the key to managing the battlespace and exploiting information superiority as enablers of all other operational and support missions. Effective C3 assures situational awareness and provides the ability to control the forces at all levels of command.*
- *CMS: Combat Management Systems are at the heart of naval vessels. Combat Management Systems integrate all the ship's sensors and information of other parties for real time situational awareness. They manage all Combat System sensors and weapons and provide planning and decision aids for the conduct of warship missions.*
- *Contingency Landing: For this kind of landing, it is assumed that the crew has enough time to react and land on a low risk area. Contingency landing areas are defined during mission preparation and are not populated. Major failures can lead to contingency landing.*
- *Emergency Landing: In this case, landing has to be performed immediately and can occur on a populated area. Hence, this kind of landing is more likely to harm people. Critical failures lead to emergency landing.*
- *MOC: The Maritime Operation Center provides a framework from which Navy commanders exercise C2 at the operational level. Command and control entails both the processes (planning, directing, coordinating, and controlling forces and operations) and systems (personnel, equipment, communications, facilities, and procedures employed by commander) as they relate to the exercise of authority and direction over assigned or attached forces and organizations. The MOC exists to streamline the operational cycle and to provide a structure for quickly and effectively establishing support for an operational level maritime commander. The MOC is an extension of the commander; its sole function is command support, and its authority is delegated to it by the commander. The span of control a commander can effectively exercise is finite. At the operational level, the commander normally delegates the authority to plan and execute tactical missions to subordinate task force or task group commanders. This enables the commander and his MOC to focus attention on the operational level and empowers subordinate commanders to employ their forces to support the commander’s intent.*
- *PADR: The Preparatory Action on Defence Research is a concrete step aimed at assessing and demonstrating the added-value of EU supported defence research and technology (R&T). The relevant results are expected to further deepen European defence cooperation, addressing capability shortfalls, and to strengthen European defence stakeholders. The European Commission launched the PADR with a view of developing a future European Defence Research Programme as part of the EU’s next Multiannual Financial Framework.*

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- *UAV: An unmanned aerial vehicle, commonly known as a drone, is an aircraft without a human pilot aboard. UAVs are a component of an unmanned aircraft system (UAS); which include a UAV, a ground-based controller, and a system of communications between the two. The flight of UAVs may operate with various degrees of autonomy: either under remote control by a human operator (Remotely Piloted Aircraft System) or autonomously by on-board computers.*
- *USV: Unmanned surface vehicles (USV) or autonomous surface vehicles (ASV) are vehicles that operate on the surface of the water (watercraft) without a crew. Using a small USV in parallel to traditional survey vessels as a 'force-multiplier' can double survey coverage and reduce time on-site. Military applications for USVs include powered seaborne targets and mine-hunting. Operational USVs may have offensive capability.*
- *UUV: Unmanned underwater vehicles, sometimes known as underwater drones, are any vehicles that are able to operate underwater without a human occupant. These vehicles may be divided into two categories, remotely operated underwater vehicles (ROVs), which are controlled by a remote human operator, and autonomous underwater vehicles (AUVs), which operate independently of direct human input. The latter category would constitute a kind of robot.*

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2 REFERENCES

2.1 Applicable documents

Ref.	Identification	Title
A1.	GA 801697	PADR-US-01-2017 – Grant Agreement 801697 OCEAN2020 – ANNEX I – PART B – Description of the Action

2.2 Reference documents

Ref.	Identification	Title
R1.	EU Implementing Act 2019/947 of 24th of May 2019	Commission Implementing Regulation (EU) 2019/947 of 24 May 2019 on the rules and procedures for the operation of unmanned aircraft
R2.	EU Delegated Act 2019/945 of 12th of March 2019	Commission Delegated Regulation (EU) 2019/945 of 12 March 2019 on unmanned aircraft systems and on third-country operators of unmanned aircraft systems
R3.	EASA ED Decision 2019/021/R of 9th of October 2019	Acceptable Means of Compliance (AMC) and Guidance materials (GM) to Commission Implementing Regulation (EU) No 2019/947 “Rules and procedures for the operation of unmanned aircraft”
R4.	ICAO Annex 2	Rules of the Air - Annex 2 to the Convention on International Civil Aviation
R5.	RTCA DO-365	RTAC DO-365 Minimum Operational Performance Standards (MOPS) for Detect and Avoid (DAA) Systems, RTCA, 31 May 2017
R6.	ANSI UASSC	Standardization Roadmap for Unmanned Aircraft Systems 1.0.Prepared by the ANSI Unmanned Aircraft Systems Standardization Collaborative (UASSC)
R7.	EU 2016/679	REGULATION (EU) 2016/679 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC (General Data Protection Regulation)
R8.	MCDC	All Partners Access Network, “Multinational Capability Development Campaign (MCDC),” US DoD, Honolulu, USA., 2019
R9.	Systems Engineering Handbook, V3	C. Haskins, Systems Engineering Handbook, Version 3, International Council on Systems Engineering (INCOSE), 2006

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Ref.	Identification	Title
R10.	NAF V4	NATO Architecture Capability Team, "NATO Architecture Framework Verson 4," NATO Consultation, Command and Control Board, Brussels, Belgium, 2018.
R11.	CD&E Handbook, 2018	NATO, "NATO Concept Development and Experimentation (CD&E) Handbook," Allied Command Transformation, 2018.
R12.	DSEEP 2010	IEEE, "IEEE Recommended Practice for Distributed Simulation Engineering and Execution Process (DSEEP)," IEEE Std 1730-2010, 2010.
R13.	D1.1	OCEAN2020 - Operational Requirements Analysis Report
R14.	D2.1	Reference Architecture Ocean2020
R15.	D2.1	Target Architecture Baltic Sea 2020
R16.	D2.1 Appendix	Service Interface Definitions
R17.	JAPCC Document	Future unmanned system technologies – legal and ethical implications of increasing automation, Joint Air Power Competence Centre, 2016
R18.	STANAG 4586	Standard interfaces of UAV Control System (UCS) for NATO UAV Interoperability
R19.	STANAG 4545	AIR - NATO SECONDARY IMAGERY FORMAT (NSIF)
R20.	STANAG 4609	JAIS - NATO DIGITAL MOTION IMAGERY STANDARD
R21.	STANAG 4559	NATO STANDARD ISR LIBRARY INTERFACE (NSILI)
R22.	STANAG 4607	NATO GROUND MOVING TARGET INDICATOR (GMTI) FORMAT
R23.	STANAG 5525	Joint consultation, Command and Control and Information exchange data model (JC3IEDM).
R24.	STANREC 4777	NATO Intelligence, Surveillance, and Reconnaissance Interoperability Architecture.
R25.	STANAG 7023	NATO Primary Imagery Format (NPIF).
R26.	WMS	Web Map Service (Open Geospatial Consortium).
R27.	WFS	Web Feature Service (Open Geospatial Consortium).
R28.	STANAG 4778 ADatP-4778	Metadata Binding Mechanism

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Ref.	Identification	Title
R29.	STANAG 4774 ADatP-4774	Confidentiality Metadata Label Syntax
R30.	STANAG 7149 APP-11, Ed. D	NATO Message Catalogue
R31.	STANAG 5500 ADatP-3, Ed. A	Concept of NATO Message Text Formatting System (CONFORMETS)
R32.	STANAG 3277	Air Reconnaissance Request/Task Forms
R33.	STANAG 3377	Air Reconnaissance Intelligence Report Forms
R34.	STANAG 3596	Air reconnaissance Requesting and Targeting Reporting Guide
R35.	XMPP	Extensible Messaging and Presence Protocol
R36.	STANAG 4658 (4633 (CESMO/ELINT)	Co-Operative Electronic Support Measures Operations
R37.	STANAG 4676	NATO Intelligence, Surveillance, and Reconnaissance Tracking Standard
R38.	STANAG 4162	Identification Data Combining Process
R39.	STANAG 5516 Link 16, ADatP-16	Tactical Data Exchange
R40.	STANAG 5522 Link 22, ADatP-22	NATO Improved Link Eleven (NILE) – Link 22
R41.	STANAG 7085, AEDP-7085	NATO Interoperable Data Links for ISR Systems
R42.	AdatP-33	Multi Link Standard Operating Procedures for Tactical Data Systems Employing Link 16, Link 11, Link 11B, IJMS, Link 1, Link 4, and ATDL-1
R43.	AdatP-11	Standard Operating Procedures for NATO Link-11/11B
R44.	STANAG 5511	Tactical Data Exchange – Link11/Link 11B (Vol II)
R45.	STANAG 5616	Standard for Data Forwarding between Tactical Data Systems employing Links 11/11B and Tactical Data Systems employing Link 16
R46.	STANAG 5518	Interoperability Standard for the Joint Range Extension Application Protocol (JREAP)

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Ref.	Identification	Title
R47.	STANAG 4372	SATURN – A Fast Frequency Hopping ECCM Mode for UHF Radio (secret)
R48.	STANAG 2019 APP 6a	NATO Joint Military Symbology
R49.	STANAG 4420	Display Symbology and Colors for NATO Maritime units
R50.	STANAG 7074	Digital Geographic Information Exchange Standard (DIGEST)
R51.	CFR 1910.144	Colour Codes for Marking Physical Hazards
R52.	AJP 2.1	Allied Joint Doctrine for Intelligence Procedures
R53.	AJP 2.7	Allied Joint Doctrine for Joint Intelligence, Surveillance and Reconnaissance
R54.	AIntP-14	Joint Intelligence, Surveillance and Reconnaissance (JISR) Procedures in Support of NATO Operations
R55.	AIntP-16	Intelligence Requirements Management & Collection Management (IRM&CM) Procedures
R56.	AJP 6	Allied Joint Doctrine for Communication and Information Systems
R57.	AJP 3.1	Allied Joint Doctrine for Maritime Operations
R58.	MTP-01	Multinational Maritime tactical Instruction & Procedures
R59.	CISE	Common Information Sharing Environment for Maritime Surveillance in Europe
R60.	MARSUR	Maritime Surveillance (MARSUR) project is a technical solution that allows dialog between European maritime information systems.
R61.	IEC60945 Edition 4	Maritime navigation and radio communication equipment and systems – General requirements – Methods of testing and required test results
R62.	ITU-R M 1371-4	Technical characteristics for an automatic identification system using time-division multiple access in the VHF maritime mobile band
R63.	IEC 61993-2	2001-12 Clause 15, for the AIS transmitter, receiver and DSC receiver.
R64.	ACO (a)	M. Dorigo. Optimization, learning and natural algorithms. Ph. D. Thesis, Politecnico di Milano, Italy, 1992

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Ref.	Identification	Title
R65.	ACO (b)	M. Dorigo, Th. Stützle, M. Birattari: Ant Colony Optimization. In: IEEE Computational Intelligence Magazine, December 2006, doi https://doi.org/ 10.1109/MCI.2006.329691
R66.	ACO (c)	Zeinab E. Ahmed et al.: Energy optimization in low-power wide area networks by using heuristic techniques. In: Bharat S. Chaudhari and Marco Zennaro: LPWAN Technologies for IoT and M2M Applications, Academic Press, 2020, doi https://doi.org/10.1016/C2018-0-04787-8
R67.	ACO (d)	Ş. Y. Balaman: Modeling and Optimization Approaches in Design and Management of Biomass-Based Production Chains. In: Ş. Y. Balaman. Decision-Making for Biomass-Based Production Chains. Academic Press, 2018.
R68.	ACO (e)	Ch. Blum: Ant colony optimization: Introduction and recent trends. In: Physics of Life Reviews 2 (2005), Elsevier, pp. 353–373

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3 OCEAN2020 OPERATIONAL SCENARIOS

The operational scenarios considered [R13] are the following:

- Littoral Area Persistent Surveillance – Friendly Coast (with UAS): This kind of operation can be performed in both symmetric and asymmetric warfare domains. The potential threats to be countered with these operations are small and fast vessels, illegal merchant ships, unmanned small vessels, and warships. The UAVs that can be used for performing this operation are Rotary Unmanned Aerial Systems (RUAS) and platforms labelled as Medium Altitude Long Endurance (MALE) UAS. The payload required for achieving the goals of this operations are Maritime Surveillance Radars, Electronic Support Measures (ESM), Automatic Identification Systems (AIS), and Electro Optical Systems (EOS). In the context of this kind of operations the control nodes are represented by a coastal base (Command and Control – C2, and mission) and a command ship (mission). The main aim of this kind of mission is to detect, track, recognise, and identify vessels in shipping lanes and local ports or small harbours that might represent a threat to friendly assets and/or the command ship. Moreover, it is possible to detect unusual activities and gather intelligence.
  The RUAS is deployed by a heliport located in the coastal base and it is remotely operated from there, although the pilotage can be transferred to the command ship. The data collected through the sensor systems are transferred to the command ship in order to build the RMP and then disseminated to other assets involved in the mission and the MOC via the satellite communication (SATCOM).The MALE UAS is deployed from a land-based airport and the sensor data provided to the MOC are used for building the RMP, which is later disseminated to the other platforms involved in the mission via SATCOM. Would the SATCOM be missed, data are provided to the command ship through a short-range Line Of Sight (LOS) datalink.
  The contacts of interest are identified through radars and ESM and, if the contact is within the range of the EOS, the contact is also located in order to permit identification. For larger contacts at longer ranges, the Inverse Synthetic Aperture Radar (ISAR) mode could be used for classification. If the contact is beyond the EOS range the RUAS/MALE UAS is tasked to change its flight plan and position itself to maintain eyes-on on the contact for identifying and potentially tracking it. These data are then disseminated to other platforms and the MOC for threat analysis and decision making.

- Littoral Area Persistent Surveillance – Friendly Coast (with USS): This kind of mission can be performed in both the symmetric and asymmetric warfare domains, to counter potential threats coming from small and fast vessels, illegal merchant ships, unmanned small vessels, and warships. The operation needs a time on station of 24/7, which can be achieved by using multiple USS. The main aim of this kind of mission is to complement traditional coastal radars, to detect (early warning), track, recognise and identify surface vessels in shipping lanes or in own territorial waters that might be a

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contact of interest to friendly assets (ships and shore installations) and/or the command ship. It is also possible to detect unusual activity and gather intelligence thanks to Maritime Surveillance Radars, AIS, EOS, video cameras, ESM sensors and towed array sonar for long range detection mounted on the platform. In the context of this kind of operation the control nodes are represented by a coastal base (C2 and mission) and a command ship (C2 and mission).
The USV can be either deployed from a harbour close to the Area of Operation (AOO), or it can be deployed from a surface ship already present in the AOO, to get longer operational reach. The USV can be ordered to loiter in the area from a set pattern or be piloted via SATCOM or LOS datalink. Data gathered by the mission complement the RMP, which is disseminated to other assets via SATCOM. During the phase of data gathering, should contact be beyond the range of EOS sensors, the USS can be tasked to re-position itself and get eyes-on to identify and potentially track the contact. The EOS motion imagery is then disseminated to other assets and to the MOC for contact analysis and decision making.

- Littoral Area Persistent Surveillance – Friendly Coast – Surface Threat (with UUS): The main aim of this kind of mission is to complement traditional acoustic intelligence collection to perform early warning, tracking, recognition and identification of surface vessels in own territorial waters that may be a contact of interest to friendly assets. Moreover, by the use of HF sonar or towed array sonar unusual unfriendly activities can be spotted. For this kind of mission, airborne assets and UUV can be deployed together, so to complement each other in terms of sensor coverage and to limit eventual weather/geographical constraints. The UUV can be either deployed either from a harbour close to the AOO and then sail independently or from a surface ship. The UUV can be ordered to loiter in the area from a set pattern or be piloted from a coastal base or from a command ship via acoustic datalink. The RMP is built from the mission data transmitted to the UUV to the coastal base or the command ship via acoustic datalink and is then disseminated to other assets via SATCOM.

- Littoral Area Persistent Surveillance – Friendly Coast – Submarine Threat (with UUS): The main aim of the mission is to complement traditional Anti-Submarine Warfare (ASW) with a covertly deployed asset that can be on station for extended periods of time (24/7). The goal is to detect, track, recognise and identify unfriendly submarines or unusual underwater activities in own territorial waters that might be a threat to friendly ships and shore installations.
The UUS can be either deployed from a harbour close to the or from a surface ship already present in the AOO. Moreover, the UUs can be deployed together with airborne assets, to complement each other. Data of the mission, gathered via acoustic sensors are transmitted to the coastal base or the command ship via acoustic datalink or secure

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Satellite link. Once the RMP is built, it is transmitted to other ASW assets via Satellite link.

- Littoral Area Persistent Surveillance – Unfriendly Coast (with UAS): The main aim of this kind of mission is to detect, track, recognise, and identify vessels (fast vessels, illegal merchant ships, unmanned small vessels, warships) in shipping lanes and local ports or small harbours that might represent a threat to friendly assets and/or the command ship. Moreover, it is possible to detect unusual activities and gather intelligence. The warfare domains in which this kind of mission can take place are both the symmetric and asymmetric ones. Maritime Surveillance Radars, ESM, AIS, and EOS are essential payloads for achieving the goals of this operation. The control nodes are represented by a coastal base (C2, mission) and the command ship (mission). Since the unfriendly coast does not provide any friendly base required for launching the large RUAS and MALE UAS, this mission can only be performed through the deployment of UAS. The UAS are deployed from the host ship and the sensor data are shared with it to build the RMP. Then, these data are disseminated to other platforms involved in the mission and the MOC via the SATCOM. The contacts of interest are identified through the radars and ESM and, if the contact is within the range of the EOS, the contact is also located in order to permit identification. As it is foreseen for the previous scenario, ISAR mode could be used for classification of larger contacts at larger ranges and, if the contact is beyond the EOS range, the UAS flight plan can be changed to maintain eyes-on on the contact. The data collected through the EOS motion imagery are then disseminated to other platforms and the MOC for threat analysis and decision making.

- Littoral Area Persistent Surveillance – Unfriendly Coast (with USS): In the context of this kind of operation the control nodes are represented by a host ship (C2 and mission) or a coastal base via SATCOM.
  The main aim of this kind of mission is to operate close to unfriendly territory in both symmetric and asymmetric warfare domains, to detect, track, recognise and identify unfriendly vessels - small and fast vessels, warships and fixed installations - and collect intelligence of enemy activities, without jeopardising own forces. This task requires surveillance at long range and for extended periods of time (days-weeks-months), which can be achieved by using multiple USS. The USV is overtly or covertly deployed from a host or mother ship. Mission data collected via Maritime Surveillance Radar, AIS, EOS, ESM sensors and towed array sonar are then transmitted to the MOC via secure SATCOM, where a RMP is built and then disseminated to other naval assets always via SATCOM. The latter element is crucial not to reveal the existence and position of the other assets. In order to maintain covertness of position and activities, a passive search with ESM sensors or towed array sonars can be beneficial.
  If the target is within the range of the EOS, the sensor can slave to the contact location to allow identification. For larger contacts at longer ranges, the ISAR mode can be used

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for classification. If the contact is beyond the EOS range, the USS can be tasked to re-position itself for maintaining eyes-on on the contact in order to identify and potentially track it. The EOS motion imagery data is then disseminated to other platforms and the MOC for threat analysis and decision making.

- Littoral Area Persistent Surveillance – Unfriendly Coast (with UUS): The main aim of the mission is to operate covertly in unfriendly territorial waters without putting in danger own forces in order to collect intelligence of unfriendly and hostile daily activities. This task requires surveillance at long range from own territory and for extended periods of time (days-weeks-months).
  The UUS is covertly deployed from a surface host or mother ship or from a submarine. After launch, it covertly transits to the mission area. The mission data collected is either transmitted to the MOC via secure Satellite link at set intervals or collected after the mission, on-board the mother ship or submarine. The mission data is then analysed and disseminated to other naval assets via Satellite link. The latter element is crucial not to reveal the existence and position of the other assets. In this regard, a passive search with ESM sensors or towed array sonars is very beneficial in order not to reveal the position and activities of the UUS. Target of interests are detected, recorded and identified by tower array sonar or ESM. Moreover, contacts on the seabed can be identified by HF active sonar.
  One relevant risk in this kind of mission is the recovery operation of the UUS, since it can be "infected" with explosives devices or other dangerous systems that could harm the mother vessel.

- High Sea Persistent Surveillance (with UAS): The primary objective of the mission is to detect, track, recognise, and identify small and fast vessels, illegal merchant ships and warships that may represent a threat. The potentially threatening vessels could include enemy assets (possible high capability) or other platforms intended for pirate, terrorist, and drug/smuggling activities. Therefore, this mission can be set in place both in the symmetric and asymmetric warfare domains. The platforms that can be used for this activity are RUAS and MALE UAS. Another particular task inherent to this mission involves the surveillance at a distance around shipping lanes and harbours for long periods of time for observing the POL with the objective of detecting unusual activities or threats based on the everyday activities in the area. If multiple UAS/multiple MALE UAS are used, the time on station will be 24/7.
  The RUAS is launched by the host ship, and its control nodes are represented by the host ship (C2 and mission).The host ship receives the data collected by the RUAS and uses them for building the RMP which is later disseminated to the other assets employed in the mission and the MOC via the SATCOM.
  The MALE UAS is deployed from an airport. For the MALE UAS, the control nodes are represented by the coastal base. The mission sensor data are provided to the MOC and

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used for building the RMP which is then disseminated to other platforms via the SATCOM connected to the MOC. Would the SATCOM be missed, the MALE UAS provides the data to the command ship through a short-range Line Of Sight (LOS) datalink.
The payload to be carried for achieving the aims of the mission include Maritime Surveillance Radars, ESM, AIS, and EOS. The contacts of interest are identified through the radars and ESM. Would the contact be in an area internal to the EOS range, these sensors provide information on the location in order to permit identification. For larger contacts at longer ranges, the ISAR mode can be used for classify the target. If the contact is beyond the EOS range the RUAS/MALE UAS is tasked to interrupt its flight plan and position itself to maintain eyes-on on the contact for identifying and potentially tracking it. The data collected through the EOS motion imagery are then disseminated to other platforms and the MOC for threat analysis and decision making.

- <u>High Sea Persistent Surveillance (with USS):</u> In this operational scenario, the warfare domain can be both symmetric and asymmetric. The main aim of this kind of mission is to detect, track, recognise and identify surface vessels in open ocean that might be a contact of interest. They could include enemy assets (with possible high capability) that can be used for pirate, terrorist, drugs and smuggling activities. The task requires surveillance at a distance around the normal shipping lanes and for extended period of time, to observe the maritime pattern of life of the potential contact, with the aim of gathering intelligence on daily activity and possibly detecting unusual activities.
The USV is deployed from a host or command ship and it can be ordered to loiter in the area from a set pattern or it can be piloted from the mother vessel via SATCOM or LOS data link. The mission data provided to the host ship is used to build the RMP which is then disseminated to other assets via LOS data link and to the MOC via SATCOM.
The contacts of interest are identified and if within range of the EOS, the sensor can slave to the contact location to allow identification. For larger contacts at longer ranges, the ISAR mode of the radar or ESM sensors and towed array sonar for long range detection can be used for classification. If the contact is beyond the EOS range, the USS can be tasked to re-position itself to maintain eyes-on in order to identify and potentially track the contact. The EOS motion imagery data is then disseminated to other assets and to the command ship for contact analysis and decision making.

- <u>Foreign Naval Base Protection (with UAS):</u> The task includes surveillance around the host vessel or High Value Unit (HVU) in foreign ports in order to detect, track recognise and identify unfriendly contacts that can be on the surface or underwater and on land. The potential threats may be small and fast vessels, unmanned small vessels, warships, divers, missiles, armoured vehicles, and personnel. The contacts can be of interest for the host vessel or other assets such as military or civilian infrastructures. As a result of

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the detection and identification phase, a certain degree of protection could be needed. The mission can be included within the symmetric or asymmetric warfare frameworks. The mission requires the deployment of multiple unmanned assets (UAVs, USVs, and UUVs). Regarding the UAVs, both a RUAS and a MALE UAS are involved. The UAS are deployed from a host ship, which is currently within the harbour. The role of the UAS is to carry out surveillance activities around the harbours and the surrounding areas. The MALE UAS is deployed from an airport for carrying out a persistent, silent, and not eye detectable reconnaissance, (POL) investigation, and surveillance role around the harbour and in the surrounding areas.

The USV can be deployed by the host ship, while multiple UUVs can be deployed either from the host ship or directly by the USV. The UAS and the MALE UAS identify the local civilian airport as a no-fly zone. The payloads to be carried are Maritime Surveillance Radar, AIS, EOS, High Frequency (HF) sonar (which represent the main sensor for the USS and UUS) and Video camera. The primary sensor for the RUAS and MALE UAS is the EOS. The Synthetic Aperture Radar (SAR) modes of the radar can be used for providing high-resolution images of harbours and land installations. Moreover, the Ground Moving Target Indicator (GMTI) modes can be used for identifying and tracking moving vehicles.

The control nodes are represented by the host ship (C2 and mission), the airport for the MALE UAS, and the command centre for the USS and UUS.

- Home Naval Base Protection (with USS): In this kind of operation, the warfare domain can be both symmetric and asymmetric. The task of this operational scenario includes surveillance around the host vessel or High Value Unit (HVU) in port in order to detect, track, recognise and identify contacts of interest, which can appear both on water and in the water. Indeed, the potential threats of this scenario are small and fast vessels, unmanned small vessels, warships, divers, mines, floating and bottomed IED and missiles. A time on station of 24/7 is required, which can be achieved by using multiple USS.

  The USV can be deployed from a host ship that is already within the harbour or from a boat ramp, a lorry or any other vehicle. The USV can then loiter in the harbour area from a set pattern or it can be piloted from a coastal base or from a command ship or command centre via LOS datalink. After detection and identification, protection could be necessary. The expected short range from detection to a potential attack requires short reaction time and a firm chain of command.

  In this kind of mission, the main sensor is represented by the short-range maritime radar and EOS and video cameras for evidence collection. The SAR mode of the radar can be used to provide high-resolution images of harbours and land installations. The control nodes are represented by a host ship (C2 and mission) or a command centre for USS.

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- Home Naval Base Protection (with UUS): The task involves under water (UW) surveillance around the host vessel or HVU in port in order to detect, track, recognise and identify UW and surface contacts - small and fast vessels, unmanned small vessels, warships, divers, mines, floating and bottomed IED - of interest that might be a threat to the host vessel or to military and civilian infrastructures. In this mission, after detection and identification, protection could be needed. The proximity to civilian ships and infrastructures and the expected short range from detection to a potential attack require short reaction time and a firm chain of command with well-developed ROE's.
 The UUV can be deployed from a host ship that is already within the harbour or from a boat ramp, a lorry or any other vehicle. HF sonar, EOS and video cameras for evidence collection are the main sensors for this kind of mission. The MOC is updated on the RMP from the command ship.

- Choke Point Transit Surveillance (with UAS): This mission can be performed in both symmetric and asymmetric warfare domains and it is performed through the deployment of multiple platforms (UAVs, USVs, and UUVs). The goal of the mission is to monitor narrow areas – such as straits and channels – both at distance and around the host vessel and the other assets involved in the mission in order to detect, track, recognise, and identify targets that can represent a threat to the host vessel. The operational scenarios represent a situation in which a military operation is in progress and the host ship will be assigned a segregated flight area where it can operate the UAS.

 The RUAS is launched by the host ship for conducting surveillance operations ahead and around the ship. The USV is deployed by the host ship for conducting mine surveillance tasks which may include the launch of UUVs. The latter may be deployed directly from the ship.
 The payloads required are Maritime Surveillance Radar, AIS, EOS, HF sonar and video camera (mainly for USV and UUVs). The control node is represented by the host ship. The data provided by the radar track and the AIS are passed to the command ship for building the RMP which is then disseminated to the other assets deployed and to the MOC via the SATCOM. The SAR mode of the radar can be useful for providing high-resolution radar images of harbours and land installations. The GMTI modes can identify and track moving vehicles.
 The data collected by the HF sonar and video camera installed on the USV and UUVs can be reported back directly to the command ship or via the RUAS.

- Choke Point Transit Surveillance (with USS): The warfare domain of this operational scenario can be both symmetric and asymmetric. The potential threats are small and fast vessels, unmanned small vessels, warships, floating IED and mines, while a time on station of 24/7 is required. The task includes UW surveillance and monitoring of narrow

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hazardous areas such as straits and channels at some distance or time ahead and around of a transiting vessel, an HVU or a naval task force.

The goal of the mission is to detect and identify any contact of interest. Nonetheless, while the search might take long time and it should start well before the friendly units approach the hazardous are, the range from detection to a potential attack requires short reaction time and a solid chain of command.

The payload necessary to the operation are Maritime Surveillance Radar, AIS, EOS, video cameras, ESM sensors for long-range detection of surface contacts, HF sonar for mine detection and SATCOM.

The USV is deployed from a host ship and it can then loiter in the hazardous area from a set pattern or it can be piloted from the command ship via SATCOM. The mission data provided to the command ship is used to build the RMP which is then disseminated to other assets and to the MOC via SATCOM.

- <u>Choke Point Transit Surveillance (with UUS):</u> In this kind of operation, the warfare domain can be both symmetric and asymmetric. The potential threats are mines, floating IED, warships, small fast surface vessels or boats protecting the minefield and submarines. The goal of the mission is to detect and identify any contact of interest. Nonetheless, while the search might take long time and it should start well before the friendly units approach the hazardous are, the range from detection to a potential attack requires short reaction time and a solid chain of command. The UUV is deployed from a host ship in order to carry out the surveillance mission around the ship or the task force; then the UUV can loiter in the hazardous area from a set pattern.

  A time on station of 24/7 is required for this kind of mission, which can be achieved by using multiple UUS. HF sonar, the towed array sonar for longer range detection, and video cameras for evidence collection are the necessary payloads to the mission. The mission data provided to the command ship is used to build the RMP which is then disseminated top other assets and to the MOC via SATCOM.

- <u>Mine Counter Measures Support (with UAS):</u> This operational scenario represent an operation in which Mine Counter Measures (MCM) Force has been sent ahead to clear the approach lane for the amphibious assets that have to perform a landing. The potential threats are indicated as sea mines, floating and bottom Improvised Explosive Devices (IEDs) dropped from small fast surface vessels or boats protecting the minefield, and submarines. The scenario can be applicable to both symmetric and asymmetric warfare domains. In this scenario UAS can be deployed in support of Mine Hunting Vessels, UUS, and UUSs, through the provision on over watch and with a data relay function. The UAS provides surveillance over the friendly assets and communication, while also guaranteeing the tactical and video relay between the MCM assets.

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- <u>Mine Counter Measures Support (with USS):</u> In this operational scenario, which is applicable to both the symmetric and asymmetric warfare domains, the operational scenario sees a MCM force sent ahead to clear the approach lanes for an amphibious operation. In this context, the main aim of the USS is to operate outside the landing zone in order to detect, track, recognise and identify enemy vessels, as well as to collect intelligence of enemy activities that might be a threat to the MCM force and to the amphibious forces.
  A time on station of 24/7 is required, which can be achieved by using multiple USS. The USV is deployed from a host or mother ship close to the AOO. It can be ordered to loiter in the area from a set pattern or it can be piloted from a command ship via SATCOM or short-range LOS datalink. Mission sensors - Maritime Surveillance Radar, AIS, EOS, video cameras, ESM sensors for long-range detection of surface contacts and SATCOM - can be controlled from the control node of the host ship.

- <u>Mine Counter Measures Support (with UUS):</u> In the context of a MCM force sent ahead to clear the approach lanes for an amphibious landing, the main aim of the UUS is to support the MCM force initially outside the minefield and landing zone. At later stages of the operation, the aim is to protect already cleared areas from enemy activities (and eventually report such activities), that can be mines, floating IED, warships, small and fast surface vessels, or boats protecting the minefield and submarines.
  More specifically, the mission for the UUS is to loiter in the area and to perform a sonar search in order to detect new contacts that may constitute a threat to the MCM and amphibious forces, on a 24/7 basis. The UUV can be deployed from a mother ship that operates together with the MCM force and then loiter in the area from a set pattern or be piloted from the mother vessel via acoustic datalink.
  The main sensors for this kind of operation are HF sonar, UW video cameras and acoustic and SATCOM datalink for reporting. Sonar and video images can be relayed directly to the MCM force commander for immediate analysis and decision making.

- <u>OTH reconnaissance from a naval force (with USS):</u> In this kind of operation, the warfare domain can be both symmetric and asymmetric. The main aim of this kind of mission is to protect a naval force in open ocean by detecting, tracking, recognising and identifying potential vessels of interest, including enemy assets (with high capability), pirate, terrorist, drugs and smuggling activities. This operational scenario requires surveillance at long distance and for extended time in order to get information about the enemy well before the enemy can get information about own forces. In this sense, a combination of UAS and USS could increase the operational performance.
  The USV deployed from a host ship sends data to the MOC via SATCOM, which then use them to build the RMP and disseminate it to other assets.
  The contacts of interest are identified and if within range of the EOS sensor, identification will be granted. For larger contacts at longer ranges, the ISAR mode of

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the radar, the ESM sensors and towed array sonar can be used for classification. If the contact is beyond the EOS range, the USS can be tasked to re-position itself in order to identify and potentially track the contact. The EOS motion imagery data is then disseminated to the MOC via SATCOM for contact analysis and to the command ship for decision making.

- Underwater Area Investigation (with UUS): In this operational scenario, the warfare domain can be both symmetric and asymmetric. The aim of this kind of mission is to conduct UW investigation in a small area around vital military or civilian infrastructure in order to detect, recognise and identify UW contacts of interest that might be a threat to the vital installation. Divers, mines, floating and bottom IED are the potential threats of this scenario that could appear both on the bottom and in water column. The generally short ranges for UW sensors make it necessary to reduce the size of the AOO in order to increase the probability of success, but also to have a long time on station, that can be ensured through the deployment of multiple UUS. For these reasons, this kind of operation is very time consuming.
  The UUV can be deployed from a host ship or from a boat ramp, a lorry or any other vehicle. The UUV can then loiter in the harbour area from a set pattern or it can be piloted from a coastal base or from a command ship via acoustic datalink. The payload necessary to the mission are HF sonar, video cameras for collection of evidence and acoustic datalink for reporting. The proximity to civilian ships and infrastructures and the expected short range from detection to a potential attack require short reaction time and a firm chain of command with well-developed ROEs.

- Support Amphibious Assault with RUAS (prior to amphibious landing): Before an amphibious landing takes place both in the symmetric and asymmetric warfare domains, a RUAS is tasked from a host ship to obtain and disseminate updated intelligence through a survey of the selected beach and its surrounding (both sea and land). The potential threats are coming from land-based targets. The RUAS is required to stay within the RLOS from the host ship which is also the control node. The payloads to be carried are Surveillance radar, AIS, and EOS. The images collected through the radar and EOS, possible target data and other intelligence information are used to support the planning of the amphibious landing. The RUAS is deployed by the host ship within a certain distance from the coast, and during the survey it has to remain undetected within the whole operational area.

- Support Amphibious Assault with RUAS (following amphibious landing): after the amphibious landing – in the symmetric or asymmetric warfare domains –, the RUAS is tasked to survey the route from the amphibious task group and the forward arming and refuelling point. This latter site will be flown by Attack Helicopters/Battlefield Helicopters/Support Helicopters and used by land platforms. The RUAS is launched

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from a Host Ship within a certain distance from the forward arming and refuelling point with the objective to validate the route and check locations by surveying the immediate landscape along the route for areas of interest and potential threats. In this scenario, the potential threats are originated by land targets and, therefore, the payload sensors carried by the RUAS must be capable of detecting hostile assets and personnel on the ground, IEDs, obstacles, etc.). These payload sensors are surveillance radar, AIS, EOS. When the Commander Landing Force (CLF) is established on the ground, it should be possible to disembark and install a kit with RUAS control stations and antennas which allows further use of the UAV for in-depth reconnaissance on land. In this case, the take-off and landing of the UAV would take place on the ground. The host ship represents the control node for this operational scenario (C2 and mission).

- Support Rigid Hulled Inflatable Boat (RHIB) boarding: This operational scenario refers to those activities to be performed after having received intelligence information regarding unlawful activities referring to the asymmetric warfare domain. In particular, the intelligence information acquired request detection activities on a cargo or other illegal merchant/commercial ship located in the area of operation. Several ships are already in the area and some of them are equipped with AIS while some other does not. The UAV deployed in such an operation are a MALE UAS and a RUAS. The former is launched by an airport and is tasked to provide a global picture of the area to the MOC, with location of the targets with and without AIS information for a detailed analysis and selection of suspicious ships to be identified. Then, the MALE UAS is tasked to identify a ship without AIS information and a ship with wrong AIS data. All these activities must be performed covertly – with no possibility of detection by the crew of the target. The ship with the wrong AIS data is considered as suspect, and a RHIB action is requested to a Command Ship carrying a RUAS.
  The RUAS is deployed by the Command Ship to reacquire and track the target. When the RHIBs from the Command Ship are tasked to approach and boarding the suspect ship, the RUAS provides Situational Awareness continuously. For doing so, the RUAS must be equipped with EOS and Infra-Red (IR) capability for night operations, and it must be capable of providing communication relay between the Command Ship and the RHIBs. Moreover, the RUAS can support a Search and Rescue operation if needed. The control node for this operational scenario is represented by the Ground station (C2 and mission).

- Support Manned Helo Boarding: This operational scenario represents an operation that can be conducted within the asymmetric warfare domain. In support to Law Enforcement, a commercial ship carrying out unlawful behaviour has been detected by other assets. A UAS deployed by a warship is tasked to detect, track, recognise, and identify the target and provide surveillance. After the launch of a manned helicopter (from the same warship) for approaching and boarding the illegal ship, the UAS is

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tasked to provide situational awareness during the whole operation. The required payloads are EOS sensors, and the Host Ship serves as control node.

- Support Interception – Self-Defence: Both in the symmetric and asymmetric warfare domains UAVs can play an active role in supporting interception activities in the context of self-defence. In this operational scenario, a UAS deployed by a ship is tasked to intercept and identify a contact that can represent a threat such as a fast boat – Fast Inshore Attack Craft (FIAC) type. Then, the UAS activities are intended to track and observe the target, confirming the nature of the threat and providing threat data to the Host Ship, which represent the control node for this operational scenario. When the threatening vessel enters in the reach of artillery from the Host Ship, it is engaged according to the ROE. In this context, the UAS is kept at a safe distance from the target in order to avoid damages. However, the UAS provides over watch and support for damage assessment thanks to its EOS with IR capability for night operations.

- Support Interception – Manned Helo (with hard kill engagement): A suspicious light fast boat travelling towards a friendly ship is detected by a MALE UAS during a Persistent Wide Area Surveillance Mission. The detection must happen at a certain distance from the friendly target. The tasks of the MALE UAS are to identify the suspect target, and then to track and observe for confirming the nature of the threat while remaining undetected. The threat might be posed within the symmetric or asymmetric warfare domain. The MALE UAS provides the threat picture simultaneously and in real time to the MOC (control node for C2 and mission) and to the command ship (control node for mission order). Based on the information provided by the MALE UAS, the MOC can confirm the positive Rule of Engagement to the ship which can launch a manned helicopter to neutralise the threat before it approaches the friendly target. During the engagement, the MALE UAS is tasked to observe the development and provide support for damage assessment. The required payloads are Maritime Surveillance Radar, AIS, and EOS. For night operations the IR capability provided by EOS sensor is crucial for a successful interception and to ensure correct damage assessment

- Support Interception – Manned Helo (without hard kill engagement): This operational scenario foresees the deployment of a UAS. The use of a manned helicopter results sufficient for deterring the potential threat to leave the area of interest without the need for direct engagement. During the interception made by the manned helicopter, the UAS continue to provide support through over watch activities.

- Support SSM Engagement: In this operational scenario, which is only applicable to the symmetric warfare domain, a frigate with a UAS on board is tasked to engage with SSM a warship detected and identified as hostile by a friendly asset. The UAS is deployed by the host ship with the aim of tracking and observing the contact, confirming the nature

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of the threat and providing data to the host ship (which is the control node for this kind of operation). Acting in compliance with the ROE, the contact is engaged with SMM, and the UAS – that must maintain a sufficient distance from the target in order to avoid damages – is used as a Target Report Unit (TRU). The payloads carried by the UAS are radar, AIS, and EOS.

- Engage Threat: In an asymmetric warfare context, a suspicious light fast boat (RHIB type) travelling at a fast speed towards a friendly ship has been detected by a friendly air asset (not necessarily an UAS). A UAS carrying EOS and Effector is launched by the ship (or from a friendly airport/heliport in the area) for reacquiring and identifying the suspicious boat. Then, the UAS is tasked to track and observe the contact confirming the nature of the menace. After having identified and confirmed the contact as a threat that can be engaged with respect to the ROE, the UAS is used to perform the engagement through its effector – which can be either a missile or a small calibre gun. After the engagement, the UAS is also used for the damage assessment. The IR capability provided by EOS is fundamental both for the engagement and the damage assessing activities.

- Engage Threat (with USS): In this asymmetric operational scenario, the host ship has deployed a protection screen consisting of multiple USS. A light fast boat travelling at high speed towards a maritime task force has been detected either by the host ship or the USSs. A USS is thus tasked to intercept, identify, track and observe the contact of interest, which can be a potential threat. Upon confirming the light fast boat as a menace, the USS can engage the target according to the ROE. The engagement is performed by using effectors carried by the USS (possible effectors are missiles, small calibre gun and Long Range Acoustic Device – LRAD). After the engagement, the USS is used for damage assessment. The IR capability provided by the EOS sensor is crucial both for engagement and damage assessment.

- Damage Assessment (with USS and UUS): In this operational scenario, a light fast boat (RHIB type) has been engaged and presumably destroyed in shallow waters. USS and UUS are deployed to confirm target destruction and localise the remains. The USS observes the engagement area and locates floating wreckage or debris of the destroyed target, confirming the target destruction. After the confirmation of the target destruction, the engagement area is declared safe. The UUS is then used to search and localise target remains on the sea bottom. UUS mission data is forwarded to the host ship via the USS.

- Support Naval Firing Support (NFS): This operational scenario depicts a situation that can be included in the symmetric or asymmetric warfare. In particular, an UAS based on a Host Ship is tasked to support a naval firing operations against a land-based

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objective (in this case it is possible to define the operation as NFS) or a maritime target near the enemy coast. The support provided by the UAS is mostly focused on providing surveillance, targeting/designation capability, spotter redundancy, and imagery to support Battle Damage Assessment (BDA). In order to guarantee effective support, the UAS must be equipped with surveillance radar, AIS, and EOS. For supporting the naval firing, the UAS has to identify, track, and highlight the target location, and it has to operate within a certain distance from the host ship for a defined amount of time.

- Collect Proof of Illegal Activity (with UAV,UUS,USV): The operational scenario depicting the collection of proofs of illegal activities applies to the asymmetric warfare domain, and it foresees the joint use of UAVs, USVs, UUVs and manned platforms. In support to law enforcement operations, a small commercial ship has been detected carrying out unlawful behaviour (possibly smuggling arms). The threats are represented by the cargo or the crew on board the suspect ship. A UAS deployed by a host ship (which represents the control node for the UAS) has been tasked to covertly carry out a monitoring mission with the aim of tracking the contact and providing surveillance. All the sensor data have to be stored in order to preserve evidences.
  A suspect event occurs: the UAS recognise the crew of the suspect ship dumping the overboard cargo. A mission is required and actions are taken. A manned Helicopter is deployed for approaching the suspect ship with a boarding team, and the UAS is re-tasked to provide continuous SA during the boarding operation. The new task of the UAS can be carried out overtly. In a time sensitive manner, a USV carrying UUVs (which will be released from the USV after having reached the area of interest) is launched by a host ship (different from the one that launched the UAS and that represent the control node for the USV and the UUVs) and it is tasked to localise, classify and identify the sunken cargo. In the meanwhile, the boarding team stops the commercial ship until evidence for transport of illegal goods are found. If evidences of illegal goods are found through the exploitation of data collected by the UUVs, the boarding team takes control of the commercial ship and the cargo can be recovered by a suitable Remotely Piloted Vehicle (ROV) in a slower timescale.
  The payloads to be carried are EOS, AIS, and radar for the UAS and the USS, and HF sonar and radar for the UUSs. In the case of night operation, the IR capability provided by the EOS can be crucial for achieving the objectives.

- Riverine surveillance (with UAS): in this operational scenario, a UAS deployed from a host ship, is tasked to conduct a surveillance mission along the waterways of the river. The objective of the mission is to detect potential threats such as hostile assets and personnel on the river shores in order to interdict enemy military activity and to secure the river.
  This scenario is for information purpose only and not considered further in the project.

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- Sea pollution control (with UAS and USS): Sea water pollution or potential breach of directive 2012/33/EG has been reported in a sea area within reach of a large RUAS based on land or in the vicinity of a port where a USS can be deployed. The UAS or the USS is deployed from the land base or the port to detect the quantity and type of pollution and to identify the polluting vessels if necessary. The UAS can also be employed as radio relay between naval and other governmental organisations assets operating in the area.

  This scenario is for information purpose only and not considered further in the project.

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4 RECOMMENDATIONS FOR UNMANNED SYSTEM DEPLOYMENT POLICY

4.1 Methodology

This section of the report seeks to develop requirements for future policy dealing with the deployment of unmanned systems in defence scenarios. These platforms are assumed to be deployed across the battlespace to include the underwater, surface, and air domains (space is considered outside the scope of this work). The intention is to raise awareness and to explore the key issues and risks of unmanned missions which future policy should serve to mitigate. A document which properly addresses the difficulties and specific considerations of unmanned missions will greatly enhance the uptake of these systems and could assist in future procurement. We seek to provide sufficient detail to assist in drafting this future policy.

The rapid development of unmanned platforms arises from their potential utility in conducting long duration “dull and dirty” missions in which human operators may be kept out of harm’s way. In some cases – particularly in the field of Mine Countermeasures (MCM) – unmanned platforms bring to bear better performing sensors than is currently available on manned platforms e.g. high resolution synthetic aperture sonar versus forward looking sonar deployed on Mine Countermeasure Vessels (MCMVs). In the Anti-Submarine Warfare (ASW) domain the reduced space and power availability necessitates smaller versions of traditional sensors e.g. low power active sonar or shorter passive towed arrays. Nevertheless the potential to deploy larger numbers of these low cost platforms over long durations remains an attractive prospect.

The requirement for policy derives from the multinational nature of military deployments and the growing number of industries developing various types of unmanned platforms. In the underwater domain in particular unmanned platforms have been developed that must be operated in very different ways from conventional assets. In this case they are not simply smaller unmanned versions of conventional platforms. Unlike an unmanned surface platform an underwater glider has no manned equivalent requiring different tactics and concepts of operation. Often these platforms must be deployed in large numbers (relative to the number of platform in a typical task group) and will be left to their own devises for long periods of time. This represents a challenge on a number of levels from deployment and recovery logistics through command and control and human factors.

It is important therefor that both planners and operators have standard procedures and policy that will allow them to more easily operate and integrate different platforms. Many of the points detailed in the following sections derive from a need to develop standard practise that will mitigate against the complexities of deploying unmanned platforms. Ultimately this will allow for the potential benefits of unmanned systems to be more fully realised in future missions. While this section is concerned with higher level policy, much mitigation of unmanned platform interoperability falls within the standards space. This more technical work may develop detailed instructions and software to facilitate interoperability between

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platforms. This may include communications standards and protocols together with specific message and data formats for command and control. This will allow platforms to more fully cooperate on the tactical level. The policy need not touch on these more detailed aspects but rather will highlight the need for these solutions in future multinational unmanned platform deployments, e.g. NATO standards such as multi domain, underwater communications, etc.

This work is focused on the following four policy components that will be expanded for each of the specific domains in the following sections. Terminology, Operational Requirements, Human Factors, Legal and Ethical issues were the focus areas of the Multinational Capability Development Campaign (MCDC) [R8] and serve as the basis for this work.

Terminology – developing definitions for platform types will greatly enhance the ability for multinational operators and planners to work together.

- Terminology
    - Seek to categorise platforms e.g. small, medium, and large with examples. Note that NATO has agreed a terminology.
    - Categorise the level of autonomy – from simple waypoint following, through additional obstacle avoidance to fully optimised courses of action.

- Operational requirements
    - Deployment and recovery considerations
    - Support/infrastructure requirements (e.g. mothership or airstrip etc.)
    - Communication requirements (particular issues underwater – in which limited bandwidth drives the need for greater levels of autonomy)

- Human intervention in UxVs operations
    - Mission planning – interface with robotic systems. Linked to level of autonomy e.g. operator determines waypoints, or simply provides an area of operations and relies on platform to determine the precise course of action.
    - Manned unmanned teaming – consider deployment of unmanned platforms to support/augment manned platforms.
    - Live operation concern

- Legal and ethical issues
    - Legal aspects e.g. surface autonomy linked to COLREGS
    - Ethical issues regarding arming platforms – certainly air, and possibly surface, ahead of underwater in this regard
    - Rules of engagement
    - Man in the loop – ability to take over in the event of issues which is linked to communication (bandwidth / latency)

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4.2 Recommendations for the elaboration of policies/standards related to UAV roles and military deployments

The roles of UAVs and their military deployments increased considerably in the last decades. Nonetheless, the continuously evolving characteristics of UAVs make their application constantly changing, highlighting the need for undated policies standards and regulations for their employment in military operations, taking into considerations their increasing role in the exploitation of a military mission.

In particular, the need to update policies and standards in the following main categories has been identified: terminology, operational requirements, human factors, legal and ethical issues.

4.2.1 Terminology

The terminology generally used in reference to UAV varies in terms of the considered categorisations. Therefore, in order to have a common and shared reference point, an internationally agreed categorisation is encouraged. Nonetheless, taking into account commonalities among the different categorisations of UAV platforms, the following main parameters have been identified from D1.2 table 4.1.a:

Table 1 - UAV Platform Terminology

Parameters (1)	**Level 1**	**Level 2**	**Level 3**	**Level 4**	**Level 5**	**Level 6**
Airframe type	Flapping wing	Fixed wing	Tilt body / rotor / wing	Rotary wing	Parafoil	Lighter than air
Propulsion type	Electrical	Internal Combustion Engine (ICE)	Turbo prop/Turbine	Other		
Take off / landing type	VTOL (vertical take-off and landing)	STOL (short take-off and landing) (2)	CTOL (conventional take-off and landing)			
Datalink type and range (km)	Radio line of sight up to 5	Radio line of sight from 5 to 25	Radio line of sight from 25 to 50	Radio line of sight from 50 to 200	Beyond radio line of sight (Unlimited)	
Flight altitude (ft.)	Less than 1000	1000 to 10000	10000 to 16000	16000 to 50000	More than 50000	
Endurance (h)	Less than 2	2 to 4	4 to 6	6 to 10	10 to 24	More than 24
Weight :MTOW (kg)	Less than 25	25 to 150	150 to 1500	More than 1500		
Payload capacity (kg)	Less than 5	5 to 25	25 to 75	75 to 200	More than 200	

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Parameters (1)	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
Max speed (km/h)	Less than 3	3 to 75	75 to 150	150 to 370	More than 370	
Operating wind	Less than 4 Beaufort (24 km/h)	4 to 6 Beaufort (24-44 km/h)	Less than 6 to 8 Beaufort (44-68 km/h)	8 to 10 Beaufort (68-95 km/h)	Above 10 Beaufort (>95 km/h)	
Operating rain	No rain	Light rain (IPX4 or less)	Heavy rain (IPX5 or more)			

(1) Each parameter should be considered independently, parameters are not always consistent across the system.

(2) Include hand launch, catapult launch, net recovery

4.2.2 Operational Requirements

Coming to the operational requirements, there are several aspects to be considered, and that would need to have a clearer and common definition. Among them, considerations on mission requirements, deployment and recovery, support infrastructures requirements and communication requirements will be dealt with.

Mission requirements shall identify all needed functions with the associated performances to meet mission goals. This will introduce several specifications on platforms, sensors and payloads.

Considerations on deployment and recovery. To ensure a secure, safe and straightforward deployment and recovery of the asset, a sufficient runway length, or size of the helipad, has to be ensured before the definition of the deployment details. Moreover, the radio coverage for all flight phases has to be ensured by an adequate number of antennas to be installed. The effectiveness of the radio coverage should be assessed before the deployment of assets, also by taking into account the orthographic composition of the environment. Indeed, the presence of existing infrastructures or natural hurdles may diminish the capacity of the antennas already deployed that may need to be complemented by further equipment.

Support and infrastructures requirements. The definition of support and infrastructure requirements prior to the start of the operation would be beneficial to the success of the operation. In particular, a detailed definition of the access type to the deployment area (airfield, harbour, road ...) should be defined in advance. Indeed, the physical conformation of the territory upon which the UAV can be employed, might limit the range of components to be mounted on the UAV. Again, also in regard to the fuel capacity of the UAV and the re-fuelling facilities that may be necessary for the exploitation of the mission, there is the need

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to define beforehand the amount of fuel required, as well as the potential locations for the re-fuelling capacities.
When considering the employment of UAVs in military operations also other aspects not directly related to unmanned systems have to be taken into account. For instance, all the logistical aspects of the mission (staff's and crew's facilities, bedrooms, catering, office rooms, C2 stations,…) have to be addressed. Moreover, spare parts of critical components — be they propellers or other components — as well as supporting tools should be at the availability of the personnel employed.

Communication requirements. The operational support provided by unmanned platform would be reduced if inadequate communication requirements are provided. In military operations, particularly when deploying UxVs, the secure exchange of tactical information might determine the success of the mission via information superiority. Therefore, datalink/voice link with the Command, Control, Communication, Computer and Intelligence (C4I) has to be tested in advance. Moreover, in order to ensure the good functioning of such a net-centric system, in case of SATCOM link usage, the compatibility of the mission area to the satellite covering area, as well as the complete availability of the satellite link for the entire duration of the mission, have to be tested prior to the mission. During the mission planning, the possibility of losing communication with the unmanned asset should be considered, and eventual backup options should be planned beforehand, also by foreseeing greater levels of the systems' autonomy.

4.2.3 Human intervention in UAVs operations

4.2.3.1 *Mission preparation*

The mission preparation is specific to each UAS and has to take into account its main characteristics such as the level of autonomy or velocity. The mission preparation shall:

- Define critical flight trajectories : approach, landing, take off, but also lost link cases with or without GNSS signal for all flight phases (take off, cruise flight, landing)
- Take into account platform performances in the mission configuration.
- Define safe recovery areas in case of critical failure, for all flight phases and then in the whole mission area. This shall also consider lost link cases.
- Confirm or adjust the mission area is in range of the datalink
- Perform an EMC analysis with all systems to avoid perturbation during the deployment.
- A frequency map shall be established with all links of all systems to avoid interferences between systems. This shall also consider surrounding emitter/receiver not directly concerned by the deployment (e.g. citizen telecom link)

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4.2.3.2 *Live operation*

During an operation, environmental conditions are always changing (weather conditions, other flying assets….). As a result, the UAV pilot in command should be able to get external environment change by appropriated the Human to Machine Interface (HMI).

For safety reasons and to respect rules of air, at any time during the mission, the UAV pilot shall be able to take over the control when an automatic mode is engaged. Also, the pilot shall be able to communicate with the ATC when needed.

In case of deployment for a mixt operation that combines manned and unmanned platforms, the UAV pilot shall be able to communicate with the Operation Centre and/or with the manned vehicle pilots.

4.2.3.3 *Recommendations to take into account about human factors in UAVs deployment*

- **Qualification & training:** to handle the situations that can be encountered during live operation, it is recommended that the UAV pilot have the same level of qualification required for a manned aircraft, especially when operating large UAVs.
  Crew efficiency depends on the level of training. This training must be regular and in the most representative context in terms of HMI and mission scenarios. Crew efficiency also depends on the confidence that the members have in each other. As a result, crewmembers should be trained to work together, stay humble and acknowledge their mistakes. To stay at a high level of training and always have the highest knowledge reference, switch between crews should happen regularly. However, during operation, the crew should not change.

- **Ergonomics & HMI:** for all mission phases, HMI shall be user friendly with several level of complexity (beginner, advanced, expert). This would allow suitable resource associated to the mission complexity. Since the UAV pilot is likely to have the same qualification than a manned aircraft pilot, it is recommended that HMI be similar to the ones in an airplane cockpit. Having the same environment lead to have the same quick reaction in case of event. Moreover, existing manned aircraft benefit for several decades of HMI design and it seems relevant to extend it to large UAS. With increased level of autonomy this recommendation on similarity between aircraft and UAS HMI should be reduced.
  During mission, tactic sensor operator and tactic coordinator should request flight trajectory modification to the UAV pilot in command to get the optimum payload information according to current external environment situation. As a result, the sensor operator shall be in the "cockpit" as the pilot in command to be sure they understand well each other.

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- **Before, during & after operation:** flight safety is strongly dependent on the UAV pilot behaviour during the mission. Therefore he shall follow a healthy lifestyle (no alcohol before flight, enough rest time, …). For the rest time, crewmembers shall know their personal need (biorhythm) which shall be consistent with the mission crews' schedule. Flight debriefing shall be done just after the flight with the complete crew. All crewmembers shall be able to provide any information relative to the mission.

4.2.4 Legal and Ethical Issues

From a legal stand point all air vehicle must conform to the rules of the air – in particular those related to safe navigation and collision avoidance. More information are provided in section 5.4.

The main ethical issue related to all UxS is the weaponisation and then their potential to harm or kill humans (see R17). A high level of autonomy would allow UxS to perform all ISTAR operation, even target neutralization, without any human intervention. Hence, for threat neutralisation, the issue to consider is the necessity of including a human operator in the decision process. For UAS, the control/monitoring datalink is assumed available in nominal conditions and this allows to maintain the operator in the decision loop. In some CONOPS of UxS, direct human intervention is not possible due to communication issues (e.g. UUVs). In this case, automatic target neutralization, if considered as an option, shall be addressed by taking into account all necessary mitigations and conditions to avoid accidental damages.

Another ethical issue when operating UAS is the personal data protection resulting from EOS observation. However, according to EU 2016/679 [R7] Article 2, part2 and subpart (d): "This Regulation does not apply to the processing of personal data by competent authorities for the purposes of the prevention, investigation, detection or prosecution of criminal offences or the execution of criminal penalties, including the safeguarding against and the prevention of threats to public security". Then during naval operation, this is not a legal issue.

4.2.5 Resulting recommendations for the elaboration of policies/standards related to UAV roles and military deployments

An analysis of the wide-discussed recommendations for the elaboration of policies/standards related to UAV roles and military deployments are summarised in the following recommendations:

Recommendation number	Recommendation description
D662-4.2-A	The terminology defined in table 1 shall be used for UAV platform
D662-4.2-B	To have high level of efficiency, mission requirements shall identify all needed functions with the associated performances to meet mission

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Recommendation number	Recommendation description
	goals in view to decline them into several specifications on platforms, sensors and payloads.
D662-4.2-C	For safety reasons, sufficient size for take-off and recovery area shall be ensured before definition of deployment details.
D662-4.2-D	For safety reasons, availability and capacity of communication links shall be ensured for the complete operational area before the deployment. Backup solution shall be defined to mitigate lost communication links.
D662-4.2-E	To have high level of efficiency, all support and infrastructures concerns (access to area, fuelling capacity, crewmembers logistical aspects) shall be known and solved prior the start of operation.
D662-4.2-F	For safety reasons, the mission preparation shall: ▪ Define critical flight trajectories : approach, landing, take off, but also lost link cases with or without GNSS signal for all flight phases (take off, cruise flight, landing) ▪ Take into account platform performances in the mission configuration. ▪ Define safe recovery areas in case of critical failure, for all flight phases and then in the whole mission area. This shall also consider lost link cases. ▪ Confirm or adjust the mission area is in range of the datalink ▪ Perform an EMC analysis with all systems to avoid perturbation during the deployment. ▪ A frequency map shall be established with all links of all systems to avoid interferences between systems. This shall also consider surrounding emitter/receiver not directly concerned by the deployment (e.g. citizen telecom link)
D662-4.2-G	For safety reasons, during operation: ▪ The UAV pilot in command should be able to get external environment change by appropriated HMI. ▪ For safety reasons and to respect rules of air, at any time during the mission, the UAV pilot shall be able to take over the control when an automatic mode is engaged. The pilot shall be able to communicate with the ATC when needed. ▪ In case of deployment for a mixt operation that combines manned and unmanned platforms, the UAV pilot shall be able to communicate with the Operation Centre and/or with the manned vehicle pilots.

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Recommendation number	Recommendation description
D662-4.2-H	For safety concerns, it is recommended that the UAV pilot have the same level of qualification required for a manned aircraft, especially when operating large UAVs
D662-4.2-I	Crew training must be regular and in the most representative context in terms of HMI and mission scenarios. To have high level of efficiency: ▪ crewmembers should be trained to work together, stay humble and acknowledge their mistakes. ▪ switch between crews should happen regularly. ▪ the sensor operator shall be in the "cockpit" as the pilot in command During operation, the crew should not change
D662-4.2-J	To ease crewmember selection, for all mission phases, HMI shall be user friendly with several level of complexity (beginner, advanced, expert). For safety reason: ▪ it is recommended that HMI be similar to the ones in an airplane cockpit. With increased level of autonomy this recommendation on similarity between aircraft and UAS HMI should be reduced. ▪ UAV pilot shall follow a healthy lifestyle ▪ for the rest time, crewmembers shall know their personal need (biorhythm) which shall be consistent with the mission crews' schedule. ▪ flight debriefing shall be done just after the flight with the complete crew. All crewmembers shall be able to provide any information relative to the mission
D662-4.2-K	From a legal stand point all air vehicle must conform to the rules of the air
D662-4.2-L	For ethical reason for UAV: ▪ for threat neutralisation it is recommended to have human in the loop ▪ If human in the loop is not possible, all necessary mitigations and conditions to avoid accidental damages shall be took into account.

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4.3 Recommendations for the elaboration of policies/standards related to USV military roles and deployments

4.3.1 Terminology

Key terminology for the surface domain is provided in Table 2.

Table 2 - USV Terminology

Type	Category	Notes
USV	Unmanned Surface Vehicle	An unmanned vehicle that operates on the surface (encompasses all levels of autonomy)
	Very Small USV	USV with a length less than 7 metres
	Small USV	USV with a length between 7-12 metres
	Medium USV	USV with a length between 12-50 metres
	Large USV	USV with a length > 50 metres
	Note: Rationale for classification by length was to align as close as possible to current provisions for lights by power driven vessels.	
	Wave Glider	USV that exploits wave motion for propulsion

4.3.2 Operational Requirements

The operational concerns relating to the deployment and recovery of USVs are somewhat mitigated due to existing systems on board most ships to deploy and recover their own RHIB. This will apply for small to medium USVs that are comparable in size and form to existing RHIBS. Larger unmanned surface platforms, particularly those with length greater than 50m, are likely to have sufficient endurance to allow for deployment from a nearby port and thereafter transit to the operational area. These larger platforms may be thought of as manned surrogates that will likely operate in a similar fashion.

In general, both endurance and communications bandwidth will not be a mitigating factor for most USVs since they may exploit both a combustion engine and radio frequency communications.

4.3.3 Human intervention in USVs operations

The majority of current USV designs allow for the possibility of embarking a human pilot. This may be required in some ports and harbours for instance where traffic density is high. In general however, the human pilot will be stationed either ashore or on a support platform. The high bandwidth communications link will allow the vehicle to be remotely controlled if

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desired assisted by a real time video feed of the view from the platform. Alternatively, mission planning software will likely allow for waypoints and area of operations to be configured.

To a large extent the human factor concerns of running a remote mission will be similar to those discussed in section 4.2.3 for unmanned air systems. Pilots will need to be suitably trained and likely work in teams to ensure alertness over long periods of time.

4.3.4 Legal and ethical Issues

The main recommendations on the elaboration of USV-related policies and standards focus on regulation, since this is the major obstacle to overcome when moving towards the future of autonomous vessels. The regulation body which deals with the formulation of the framework for maritime operations is the International Maritime Organization (IMO). The main conventions that the IMO maintains are:

- The International Convention on Standards of Training, Certification and Watchkeeping for Seafarers (STCW)
- The International Convention for the Safety of Life at Sea (SOLAS)
- The International Regulations for Preventing Collisions at Sea (COLREGs)
- The International Convention for the Prevention of Pollution from Ships (MARPOL)

Significant efforts are being invested to identify which parts of the currently applicable conventions have to be updated and/or amended to accommodate unmanned vessels and the main recommendations after a detailed study of the work performed within IMO are:

1. STCW: At present, the convention itself is applicable only if crew members are onboard a ship. The term “remote operator” has to be defined and the STCW Convention must be amended to reflect the changing skills requirement as a result of technological progress
2. SOLAS Chapter VII: The absence of persons on board creates risks related to the management of leakages, spillages or fires involving cargoes. As a consequence, autonomous vessels would have to adopt appropriate alternative safety measures so as to achieve the functionalities intended by the existing regulations.
3. SOLAS Chapter XI-1: The functions, rights and responsibilities as required by remote operating centres, including personnel, will have to be defined.
4. COLREGs: COLREG compliance will require a lot of work in the future. Some claim that autonomous vessels should comply with the COLREGs in their current form. However, over regulation may stifle the necessary technological development by the industry. What is certainly necessary as a first step forward is that the terminology related to a human centric approach should become less human-centric. This includes revising terms such as “ordinary practice of seaman”, “good seamanship”, “sight and hearing” among others, as well as considering the potential reduction of the level of human interaction.

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It has to be noted that wider adoption of unmanned vessels in both military and civilian roles and deployments is largely dependent on the update of the regulatory framework to reflect the related technological progress.

The main ethical issue relates to the potential weaponization of these systems as described in 4.2.4. Indeed, unmanned surface platforms have already been developed with the potential to carry torpedoes or be fitted with an automated gun (see for instance the Elbit Systems Seagull vehicle). Some concerns may be mitigated however due to the sufficient communications bandwidth allowing for any final decision to be made by a human in the loop. This is in contrast to the underwater vehicles discussed in the next section.

4.3.5 Resulting recommendations for the elaboration of policies/standards related to USV military roles and deployments

An analysis of the wide-discussed recommendations for the elaboration of policies/standards related to USV military roles and deployments are summarised in the following recommendations:

Recommendation number	Recommendation description
D662-4.3-A	The terminology defined in table 2 shall be used for USV platform
D662-4.3-B	Larger USV platforms may be thought of as manned surrogates that will likely operate in a similar fashion
D662-4.3-C	For safety reason: • a human pilot should be embarked on-board the USV • or real time video feed of the view from the platform shall be available to the remote pilot
D662-4.3-D	D662-4.2- F to D662-4.2-J apply also to USV
D662-4.3-E	The term “remote operator” of USV has to be defined and the STCW Convention must be amended to reflect the changing skills requirement as a result of technological progress
D662-4.3-F	Autonomous USV would have to adopt appropriate alternative safety measures so as to achieve the functionalities intended by the existing regulations about leakages, spillages or fire involving cargoes
D662-4.3-G	The functions, rights and responsibilities as required by remote operating centres, including personnel, will have to be defined for USV
D662-4.3-H	Regulation terminology related to a human centric approach should become less human-centric for USV
D662-4.3-I	For ethical reason for USV : ▪ for threat neutralisation it is recommended to have human in the loop

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Recommendation number	Recommendation description
	▪ If human in the loop is not possible, all necessary mitigations and conditions to avoid accidental damages shall be took into account.

4.4 Recommendations for the elaboration of policies/standards related to UUV military roles and military deployments

4.4.1 Terminology

Underwater Vehicle Terminology, as agreed by NATO MAROPSWG, is contained in Table 3.

Table 3 - Underwater Vehicle Terminology

Type	Category	Notes
UUS	Unmanned Underwater System	A system whose components include the vehicle, the supporting network, and all equipment and personnel necessary to control the unmanned underwater vehicle.
UUV	Unmanned Underwater Vehicle	An unmanned vehicle designed to operate primarily underwater (encompasses all levels of autonomy)
	Small UUV	3"-10" in diameter, capable of launching from Submarine Countermeasures or man-portable
	Medium UUV	10"-20" in diameter, nominally launched from Submarine Torpedo Tube
	Large UUV	21"-84" in diameter, capable of launch from Submarine Payload Tube
	Extra Large UUV	>84" in diameter, requires launch from support ship/shore

Multiple options to define the levels of autonomy of a system are presented in ACT Autonomous systems issues for defence policy makers. An alternative from Study Report: Unmanned Autonomous *Systems (UAxS) in the Future – Evolving Technology, Operational Implications and Opportunities, MCDC Campaign 2015-16* is given below and was further duplicated in NATO EXTAC 102 for unmanned ASW.

- **Level 0**: The operator only gathers and monitors (defined as filtering, prioritizing and understanding) all data. The operator analyses all data, predicts and interprets data. The system does not assist in or perform ranking tasks. The operator must do it all. The operator alone can execute decision.

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- **Level 1**: The operator gathers and monitors all data, with computer shadow for emergencies. The operator performs analysis and predictions, with computer shadow for contingencies. The operator interprets the data. The operator performs all ranking tasks, but the computer can be used as a tool for assistance. The operator executes decision, with computer shadow for contingencies.
- **Level 2**: The system is used for a specific mission. The system gathers and displays unfiltered, un-prioritized information for the operator. The operator still is the prime monitor for all information. The system is the prime source of analysis and predictions, with the operator shadow for contingencies. The operator is responsible for interpretation of the data. Both the operator and computer perform ranking tasks, the results from the operator are considered prime. Computer executes decision after the operator approval. The operator shadows for contingencies.
- **Level 3**: The system is used for a specific mission. The system gathers and displays all the information to the operator, but it highlights the non-prioritized, relevant information for the user. The system analyses the information to provide data and makes predictions, though the operator is responsible for interpretation of the data. Both the operator and computer perform ranking tasks but the results from the system are considered prime. Computer allows the operator a pre-programmed context-dependent time to veto before execution. The operator shadows for contingencies.
- **Level 4**: The system is tasked with a specific mission. The system gathers, filters, and prioritizes information displayed to the operator. It analyses to provide data that are integrated, interpreted and makes predictions into a result which is only displayed to the operator if result fits programmed context. The system performs ranking tasks. All results including "why" decisions were made to the operator. The system executes automatically, informs the operator, and allows for override ability during execution. The operator shadows for contingencies.
- **Level 5**: The system is tasked with a specific mission. The system gathers, filters, and prioritizes data. It integrates, interprets data and makes predictions. It performs final ranking. Final results are displayed to the operator. The system executes automatically and does not allow any the operator interaction.
- **Level 6**: Based on its knowledge of a broader environment, the system can initiate automatically a mission. The machine gathers, filters, and prioritizes data. It integrates, interprets data and makes predictions. It performs final ranking. No information is ever displayed to the operator. The machine executes automatically and does not allow any the operator interaction.

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4.4.2 Operational requirements

Logistic considerations including launch and recovery as well as support platform requirements are closely linked to the size and weight of the unmanned platforms. Deployment and recovery of maritime platforms at sea may be severely limited by environmental conditions such as wind and sea state. Those platforms that must be launched by crane from a ship will be limited in terms of sea state due to safety considerations. Recovery by crane is generally more difficult than launching and often requires the deployment of personnel in a small boat to facilitate re attaching the vehicle to the crane. Once again this presents safety concerns related to acceptable sea state. As an example CMRE launch and recovery operations are limited to sea state 3 as an absolute maximum. Recovery concerns related to the environment may be mitigated somewhat by more bespoke deployment and recovery systems which may serve to raise the sea state limitation. Alternatively, should the vehicle endurance allow, a vehicle may be placed in a loiter mode in order to wait for conditions to improve.

ROVs operations are more static, but depending on the size of the ROV, its design or its purpose, the sea state against remains a major factor in operations and launch and recovery system design becomes a critical concern.

Other aspects like communication and propulsion have to be taken into account for UUVs deployment. For example, acoustics communication raises bandwidth issues while umbilical solutions introduce constraints on platforms manoeuvrability and reduce the intervention area that also depends on available power for propulsion. More information are given about these concerns in section 8.2.4.

4.4.3 Human intervention in UUVs operations

Human factor considerations for the deployment of unmanned underwater systems primarily relate to the interaction (or lack thereof) between platform and commanding personnel. As already mentioned the communication limitations of the underwater domain necessitate platforms to operate with much greater degrees of autonomy than equivalent surface or air platforms. For this reason the mission plan may require only the definition of geospatial limits and an overall mission type – such as area search or barrier. Once deployed the platform may remain out of contact with commanding personnel for extended periods of time. Handing over responsibility to an autonomous platform in this way may represent a challenge for military planners.

Advanced autonomy already deployed on board CMRE UUVs allows the vehicles to maintain a prescribed search pattern until such time that contact with a target is made. At this point behaviour algorithms take over and allow the vehicle to make fully autonomous course alterations in order to exploit the environment and maximise the probability of remaining in contact with the target.

Given the strong impact of the underwater environment on the ability of sonar systems to detect targets, any mission planning tool will likely require a meteorological (METOC) input. Planning software should provide an estimate of the sound velocity profile and thereafter

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sonar performance (e.g. predicted detection range) throughout the scenario area. This will allow platforms to be positioned optimally accounting for regions where performance may be limited. Such a tool should also determine the number of platforms that are required to meet the mission requirements given the often limited detection ranges in comparison to the likely area to be covered.

Further human factors must be considered if the autonomous platforms are operating in conjunction with manned platforms. Water space management is a particularly important concern – especially in the presence of friendly submarines. In addition there is a component of trust that in early unmanned deployments may need to be earned. Underwater detection is often subject to large numbers of false alarms. Should human operators be alerted to spurious detections on a regular basis by the unmanned platforms they will eventually disregard this information. In this target tracks resulting from manned platforms may initially be given more credence than one arising from an unmanned asset – the performance of which may be unfamiliar to the human operator. This concern may be overcome with experience and improved classification algorithms on board the unmanned assets themselves.

In general much of the human factor concerns raised above will be mitigated over time as operators and planners gain experience of the platforms true capabilities.

4.4.4 Legal and ethical issues

From a legal stand point autonomous vessels operating on the surface must conform to the rules of the sea (refer to USVs legal issues in §4.3.4).

There are no such rules for underwater navigation. However there are concerns relating to possible collisions with blue force submarines. This is generally mitigated through enforced spatial or depth separation – requiring confidence that the unmanned platforms will indeed remain within their allocated regions. Maintaining accurate awareness of the location of underwater platforms generally requires regular surfacing for a GPS fix or maintaining underwater communications.

The main ethical issue relates to the potential weaponization of these systems as described in 4.2.4. Current thinking in the underwater domain largely requires unmanned platforms to detect and track a threat submarine. These concepts of operation assume that an unmanned platform would alert manned operators to take any further action. However, it may be the case that an unmanned system could potentially launch a torpedo (itself an autonomous platform) in order to prosecute the threat. In this case the question becomes whether a human operator would be included in the decision process. This would be dependent on communications links with the underwater network and the time for which the threat would remain within range of the lethal effector.

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4.4.5 Resulting recommendations for the elaboration of policies/standards related to UUV military roles and deployments

An analysis of the wide-discussed recommendations for the elaboration of policies/standards related to UUV military roles and deployments are summarised in the following recommendations:

Recommendation number	Recommendation description
D662-4.4-A	The terminology defined in table 3 shall be used for UUS and UUV platform
D662-4.4-B	For safety reason, UUV launch and recovery system shall be specifically design for high sea state. If not possible, the UUV should be place in a loiter mode for recovery when sea state would be acceptably safe.
D662-4.4-C	To mitigate communication limitations, the UUV mission plan may require only the definition of geospatial limits and an overall mission type
D662-4.4-D	For high efficiency, planning tool shall have meteorological input and provide estimate of sound velocity.
D662-4.4-E	For efficient human operators-unmanned UUV teaming, improved classification algorithms on board the assets shall be implemented
D662-4.4-F	Autonomous UUV would have to adopt appropriate alternative safety measures so as to achieve the functionalities intended by the existing regulations about leakages, spillages or fire involving cargoes
D662-4.4-G	The functions, rights and responsibilities as required by remote operating centres, including personnel, will have to be defined for UUV
D662-4.4-H	Regulation terminology related to a human centric approach should become less human-centric for UUV
D662-4.4-I	For ethical reason for UUV : ▪ for threat neutralisation it is recommended to have human in the loop ▪ If human in the loop is not possible, all necessary mitigations and conditions to avoid accidental damages shall be took into account.

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5 RECOMMENDATIONS FOR UAV FLIGHT SAFETY STANDARD AND PROCEDURES

5.1 Methodology

The methodology adopted to issue recommendations for UAV flight safety standard and procedures is the following:

- Consideration of OCEAN2020 Concept of Operation (CONOPS – maritime surveillance type of operations)
- Analysis of the state of the art regarding civil drones airworthiness regulation and standards
- Analysis of the state of the art regarding military drones airworthiness regulation and standards

Specifically for recommendations for integrating UAV with ATM rules:

- Consideration of OCEAN2020 demos inputs (e.g. naval military specificities, lessons learned from demos operations to be taken into account in procedures recommendations, etc …)
- Issuing of recommendations for UAV flight safety procedures (UAV integration)

Specifically for recommendations for elaboration of EU flight safety standard:

- Issuing of recommendations for UAV flight safety standard (UAV integration)

5.2 OCEAN2020 CONOPS

This section sums up the CONOPS detailed in D1.1 deliverable focusing only on flight safety aspect. According to D6.6.1 UAVs could be launched and recovered from a military vessel or from a military airfield.

5.2.1 Operational View

Management of Air and Water Space: The safe management of manned and unmanned platforms in the area of operations in accordance with international guidelines. There are many actors involved in this activity. In particular, airspace or water space controllers, launching platforms, Civilian and Military aviation and maritime authorities, Civilian aircrafts and vessels present in the area are involved. The launching platforms should notify the Air/Water space manager of the planned operation in case the timetable allows it. Before launching an unmanned asset, the launching platform has to request permission, and they have to communicate the end of operations to the Air/Water manager. If the permission for operating any asset is not granted, the mission is considered as failed because of the impossibility of safely operating the assets.

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5.2.2 Operational Scenarios

The operational scenarios considered are the following:

- Littoral Area Persistent Surveillance – Friendly Coast: This kind of operation can be performed in both symmetric and asymmetric warfare domains. The UAVs that can be used for performing this operation are Rotary Unmanned Aerial Systems (RUAS) and platforms labelled as Medium Altitude Long Endurance (MALE) UAS.
  The RUAS is deployed by a heliport located in the coastal base and it is remotely operated from there, although the pilotage can be transferred to the command ship.
  The MALE UAS is deployed from a land-based airport.
  If the contact is beyond the EOS range the RUAS/MALE UAS is tasked to change its flight plan and position itself to maintain eyes-on on the contact for identifying and potentially tracking it.

- Littoral Area Persistent Surveillance – Unfriendly Coast (with UAS): This kind of operation can be performed in both symmetric and asymmetric warfare domains. Due to the missing of friendly bases required for the deployment of MALE, this mission can only be performed by using a RUAS, which is deployed from a host ship.
  If the contact is beyond the EOS range, the UAS utilised in the mission is tasked to interrupt its flight plan and re-tasked to position itself for maintaining eyes-on on the contact. This way, it can be possible to identify and potentially track it.

- High Sea Persistent Surveillance (with UAS): This mission can be set in place both in the symmetric and asymmetric warfare domains. The platforms that can be used for this activity are RUAS and MALE UAS.
  The RUAS is launched by a host ship. For the RUAS, the control nodes are represented by the host ship (C2 and mission). The MALE UAS is deployed from an airport. For the MALE UAS, the control nodes are represented by the coastal base.
  If the contact is beyond the EOS range the RUAS/MALE UAS is tasked to interrupt its flight plan and re-position itself to maintain eyes-on on the contact to perform identification and potentially to track it.

- Foreign Naval Base Protection (with UAS): This mission can be included within the symmetric or asymmetric warfare frameworks, and requires the deployment of multiple unmanned assets (UAVs, USVs, and UUVs). For what concerns the UAVs, both a RUAS and a MALE UAS are involved. The UAS is deployed from a host ship which is currently within the harbour, while the MALE UAS is deployed from an airport. The role of the UAVs is to carry out surveillance activities around the harbours and the surrounding areas.

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- Choke Point Transit Surveillance (with UAS): This mission can be performed in both symmetric and asymmetric warfare domains and it is performed through the deployment of multiple platforms (UAVs, USVs, and UUVs).
  Regarding the UAVs, the RUAS is launched by the host ship for conducting surveillance operations ahead and around the ship to which a segregated flight area, where the UAS can operate, is assigned.

- Mine Counter Measures Support: This operational scenario, not reporting flight related information, represents an operation in which Mine Counter Measures (MCM) Force has been sent ahead to clear the approach lane for an amphibious landing. The potential threats are indicated as sea mines, floating and bottom Improvised Explosive Devices (IEDs) dropped from small fast surface vessels or boats protecting the minefield, and submarines. The scenario can be applicable to both symmetric and asymmetric warfare domains. The MCM Force comprises a Mine Hunting Vessels, UUS, and UUSs. An UAS can be deployed for supporting the operations through the provision on over watch and with a data relay function. The UAS provides surveillance over the friendly assets and communication, while also guaranteeing the tactical and video relay between the MCM assets.

- Support Amphibious Assault with RUAS (prior to amphibious landing): Before an amphibious landing takes place both in the symmetric and asymmetric warfare domains, a RUAS is deployed by a host ship within a certain distance from the coast. The RUAS is required to stay within the RLOS from the host ship which is also the control node, and to remain undetected within the whole operational area.

- Support Amphibious Assault with RUAS (following amphibious landing): After the amphibious landing – in the symmetric or asymmetric warfare domains –, the RUAS is tasked to survey the route from the amphibious task group and the forward arming and refuelling point. The RUAS is launched from a host ship.
  When the Commander Landing Force (CLF) is established on the ground, it should be possible to disembark and install a kit with RUAS control stations and antennas which allows further use of the UAV for in-depth reconnaissance on land. In this case, the take-off and landing of the UAV would take place on the ground.

- Support Rigid Hulled Inflatable Boat (RHIB) boarding: This operational scenario is performed in the asymmetric warfare domain. The UAV that can be deployed in such an operation are a MALE UAS and a RUAS. The former is launched by an airport and is tasked to provide a global picture of the area to the MOC. Then, the MALE UAS is tasked to identify a ship without AIS information and a ship with wrong AIS data.
  The ship with the wrong AIS data is considered as suspect, and a RHIB action is requested to a Command Ship carrying a RUAS. Thus, the RUAS is deployed by the

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Command Ship to reacquire and track the target and to provide Situational Awareness continuously.

- Support Manned Helo Boarding: This operational scenario represents an operation that can be conducted within the asymmetric warfare domain. In support to Law Enforcement, a UAS deployed by a warship to detect, track, recognise, and identify the target and provide surveillance.

- Support Interception – Self-Defence: Both in the symmetric and asymmetric warfare domains UAVs can play an active role in supporting interception activities in the context of self-defence. In this operational scenario, a UAS deployed by the Host Ship to which it provides data. During the engagement of the contact, the UAS is kept at a safe distance from the target to avoid damages.

- Support Interception – Manned Helo (with hard kill engagement): This scenario does not report flight related information._ During the Support interception mission, a suspicious light fast boat travelling towards a friendly ship is detected by a MALE UAS during a Persistent Wide Area Surveillance Mission. The detection must happen at a certain distance from the friendly target. The tasks of the MALE UAS are to identify the suspect target, and then to track and observe for confirming the nature of the threat while remaining undetected. The threat might be posed within the symmetric or asymmetric warfare domain. The MALE UAS provides the threat picture simultaneously and in real time to the MOC (control node for C2 and mission) and to the command ship (control node for mission order). Based on this information, the MOC can confirm the positive ROE to the ship which can launch a manned helicopter to neutralise the threat. During the engagement, the MALE UAS is tasked to observe the development and provide support for damage assessment.

- Support Interception – Manned Helo (without hard kill engagement): This operational scenario can be applied to both symmetric and asymmetric warfare domains. The UAS is deployed from the host ship, in support to a manned helicopter.

- Support SSM Engagement: In this operational scenario which is only applicable to the symmetric warfare domain, a frigate with a UAS on board is tasked to engage with SSM a warship detected and identified as hostile by a friendly asset. Acting in compliance with the ROE, the contact is engaged with SMM, and the UAS, deployed by the host ship, is used as a Target Report Unit (TRU).

- Engage Threat: In an asymmetric warfare context, a UAS is launched by a ship (or from a friendly airport/heliport in the area) for reacquiring and identifying a suspicious light fast boat previously detected by a friendly air asset (not necessarily an UAS).

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- Support Naval Firing Support (NFS): This operational scenario does not report flight related information. The Support NFS scenario depicts a situation that can be included in both the symmetric and asymmetric warfare domains. In particular, an UAS based on a Host Ship is tasked to support a naval firing operations against a land-based objective (in this case it is possible to define the operation as NFS) or a maritime target near the enemy coast. The support provided by the UAS is mostly focused on providing surveillance, targeting/designation capability, spotter redundancy, and imagery to support Battle Damage Assessment (BDA). For supporting the naval firing, the UAS has to identify, track, and highlight the target location, and it has to operate within a certain distance from the host ship for a defined amount of time.

- Collect Proof of Illegal Activity (with UAS, USS and UUS): This operational scenario applies to the asymmetric warfare domain and foresees the joint use of UAVs, USVs, UUVs and manned platforms. For what concerns the use of UAS - in support to law enforcement operations - a UAS is deployed by a host ship, which represents the control node for the UAS.

- Riverine surveillance: A UAS is tasked to conduct a surveillance mission along the waterways of the river and is deployed by a host ship. This scenario is for information purpose only and not considered further in the project.

- Sea pollution control: Sea water pollution has been reported in a sea area within reach of a large RUAS based on land or in the vicinity of a port where a USS can be deployed. This scenario is for information purpose only and not considered further in the project.

5.3 Analysis of state of the art regarding airworthiness regulation and standard

5.3.1 Civil Regulation

The main reference in the regulation of UAVs in the field of civil aviation is the Commission Implementing Regulation (EU) 2019/947, on the rules and procedures for the operation of unmanned aircraft, and the Acceptable Means of Compliance (AMC) and Guidance Material (GM) to Commission Implementing Regulation (EU) 2019/947 (R1, R2,R3).

On request by the European Commission, Member States and other stakeholders, EASA developed a proposals for an operation centric, proportionate, risk- and performance-based regulatory framework for all unmanned aircraft (UA). A general concept, establishing three categories of UAS operations ('open', 'specific' and 'certified') with different safety requirements, proportionate to the risk, was proposed by EASA and endorsed by the European Union Commission.

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The proposed regulation has taken into consideration the developments in the international arena e.g. work done in the International Civil Aviation Organisation (ICAO); in the Joint Authorities for the Rulemaking of Unmanned Systems (JARUS) and in the USA (Federal Aviation Administration- FAA).

The new European drone rules will come into force as of 1st July 2020.

The three main categories of UAS operations, considering the risks involved are:

- “open”: does not require a prior authorisation by the competent authority nor a declaration by the UAS operator before the operation takes place;
- “specific”: requires an authorisation by the competent authority before the operation takes place, taking into account the mitigation measures identified in an operational risk assessment, except for certain standard scenarios where a declaration by the operator is sufficient or when the operator holds a light UAS operator certificate (LUC) with the appropriate privileges;
- “certified”: requires the certification of the UAS, a licensed remote pilot and an operator approved by the competent authority, in order to ensure an appropriate level of safety.

In October 2019, EASA published the Acceptable Means of Compliance (AMC) and Guidance materials (GM) to Commission Implementing Regulation (EU) No 2019/947 “Rules and procedures for the operation of unmanned aircraft” (R3). The document includes the description of a risk assessment methodology to evaluate the danger of an UAS operation and to identify mitigation measures to make the operation safe.

Specific category of UAS operations

The methodology for conducting this risk assessment of UAS operations in the specific category is called SORA (Specific Operation Risk Assessment) and offers a very structured approach to evaluate all aspects and identify mitigations and safety objectives. This document recommends a risk assessment methodology to establish a sufficient level of confidence that a specific operation can be conducted safely.

The categories of harm considered in SORA are essentially fatal injuries to third parties on the ground; fatal injuries to third parties in the air; or damage to critical infrastructure. This methodology allows the evaluation of the intended concept of operation and a categorization into 6 different Specific Assurance and Integrity Levels (SAIL). It then recommends operational safety objectives (OSOs) to be met for each SAIL.

A mapping between standards (existing or under development) from relevant SDOs (EUROCAE, ASTM, ISO, SAE I, ASD-STAN, RTCA, etc …) and SORA OSOs requirements is currently on going.

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Typically fixed wing drones could be operated safely for maritime surveillance activities, by conducting a risk assessment of this type of operation using SORA methodology, putting into place mitigations derived from this analysis, and demonstrating that the resulting safety objective requirements are fulfilled.

Certified category of UAS operations

EASA is currently working on the rulemaking task relative to certified category of UAS operations.

A Notice of Proposed Amendment (NPA) is planned in Q3 2020. It will cover in a first step 3 types of operations, such as IFR operations of certified UAS cargo flying in airspace classes A-C, UAS Operations in urban environment (including UAS VTOL type carrying passengers; i.e. air taxis; and small UAS cargo providing delivery services).

Regarding UAS product certification, the EASA Special Conditions (SC) that can be applied are the following:

- SC-RPAS.1309-01
- SC-RPAS.FC (Flight Control Systems)
- SC-UAS.C2 (Command and Control (C2) Link)
- SC-RPAS.101-01 (RPA Electronic Equipment Fault Detection & Isolation)
- SC-RPAS.RPS-01 (Remote Pilot Station)
- SC-RPAS.CNS-01 (Required Communications, Navigation and Surveillance)

In parallel, JARUS WG-3 (Airworthiness) issued certification specifications:

- ⇨ CS-LUAS (Recommendations for Certification Specification for Light Unmanned Aeroplane Systems, applicable to fixed wing UA with a Maximum Certificated Take-off Weight (MTOW) not exceeding 750 kg).
- ⇨ CS-LURS (Certification Specification for Light Unmanned Rotorcraft Systems, applicable to Light Unmanned Rotorcraft maximum certified take-off weights not exceeding 750 kg).
- ⇨ CS-UAS (Recommendations for Certification Specification for Unmanned Aircraft Systems, MTOM not to exceed 8618 kg for UA without VTOL capability and 3175 kg for UA with VTOL capability).

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5.3.2 Military regulation

The table below reports the STANAGs that currently regulate RPAS in the field of military aviation among the NATO member states, according to the Maximum Take Off Weight (MTOW) of the UAV.

UAS	MTOW kg	STANAG
FIXED WING	< 150	4703
	150-20.000	4671
ROTARY WING	< 150 (>66 J)[1]	4746
	150 – 3.175	4702

Table 4 - STANAGs applicable to military UAV

As it is highlighted, both fixed and rotary wing drones need to satisfy the different requirements set in the four main STANAG that apply. For Rotary wing drones STANAG 4702 - AEP-80 is used to provide an airworthiness code for Rotary Wing Unmanned Aerial Systems which is derived from EASA CS-27 amendment 2 requirements, supplemented by elements from STANAG 4671. In particular, EASA CS-27 “Certification Specification for Small Rotorcraft” provides an airworthiness code applicable to small (manned) rotorcraft with maximum weights of 3.175 kg and lays down the requirements for the following areas: flight phases and characteristics, strength requirements, design and construction, powerplant, equipment, and operating limitations and information. To these areas, STANAG 4702 – AEP-80 adds the requirements for two more sectors, namely command & control data link – communication system and UAV control station, which are specific to unmanned systems.

The applicable Certification Specifications (CSs), that are valid in both the civil and military domains, are used as the base for the certification of each specific unmanned aircraft together with additional conditions or requirements agreed with the authorities and associated to the RPAS spectrum usage and the applicable design features. It has to be taken into account the possible lack of some specific standard or Acceptable Means of Compliance (AMC) related to the design that also has to be identified together with authorities. This situation provides to the certification authorities with an even more important role in the certification process. The standards that are used as reference in the certification are produced by different organizations, associations or authorities such as SAE, EUROCAE, EASA, etc. Even if that does

[1] According to a NATO case study, a 66J energy falling body is the hazard limit for a human being.

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not differ from the usual, differences are present when considering the procedures to follow in order to receive the airworthiness certification. Differently from what happens for manned aircrafts, there is a very limited (if not none) use of bilateral agreements at national level that speed-up the concession of the airworthiness certification for those assets that already received it from the country with which the agreement is in place. This particular aspect underlines the importance of achieving shared and common standards for the issue of the required certification. In this regards, under the guidance of the EDA, the Military Airworthiness Authorities Forum (MAwA) aims at developing synergies among national authorities to harmonise processes related to airworthiness certifications, although a greater effort should be done in the field of unmanned systems. Inside this framework, the Military RPAS Airworthiness Regulatory framework (ARF) Working Group, is especially tasked to find, together with national authorities, ways to streamline the airworthiness certification processes at European level.

For the military Rotary Wing Unmanned Aerial Systems and from the point of view of safety analysis, the AEP-80 standard and associated requirement USAR-RW.1309 identifies and recommends the use of ARP 4761 as an AMC. The analyses carried out associated to this standard includes FHA at the system level; FHA, PSSA and SSA of their subsystems with functionalities whose failure conditions are catastrophic or hazardous. More specifically, the FHA consists of identifying all the functions at the level under study, describing the failure conditions associated with these functions and determining the effects and severity of these failure conditions. The PSSA and SSA address all significant failure conditions identified in the FHA and aim at justifying their compliance with the safety objectives set by USAR-RW.1309 that relevantly focuses on the safety of the overflown. Moreover, the ARP 4754A evaluates also the DAL of the equipment, using DO-178B for SW and DO-254 for HW. These standards provide a complete set for the analysis of the system and Subsystems in order to show the compliance with the safety objectives.

Together with these design objectives, the approximation of the evaluation of the safety of the operation is also very important and to perform an Operational Risk analysis, and a hazard assessment of the operation provides a very valuable information. In this regard, the AMC and GM to Commission Implementing Regulation (EU) 2019/947 provide SORA methodology for conducting an operational risk assessment, in order to evaluate the safety risks involved with the operation of UAS of any class, size or type of operation (including military, experimental, research and development, and prototyping, for both fixed wing and rotary wing drones). It is particularly suited, but not limited to, “specific” operations for which a hazard- and risk assessment is required, as established by Article 11 of the Commission Implementing Regulation (EU) 2019/947.

Also associated with the safety of the design and operation of RPAS, the importance of regulations regarding the use of airspace for operation with RPAS or the use of frequencies for data links should not be forgotten. These aspects are nationally regulated and the authorizations or requirements may involve different organizations or authorities and do not

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facilitate operations in different countries. With regard to data link systems, the STANAG 4702-AEP-80 provides some standards for the regulation of command and control data link subsystems for Rotary Wing UAS, while Air Traffic Control (ATC) communication and payload data link are regulated by Operating manuals. In particular, specific requirements are set in order to ensure protection against electromagnetic interferences and vulnerabilities, as well as protection against electrostatic, lightning and electromagnetic environment (EME) hazards. Moreover, data link loss strategy must be established among the emergency measures, including an autonomous reacquisition process in order to try to re-establish in a short reasonable time the command and control data link.

The regulations regarding crew licenses must also be taken into account, in which case STANAG 4670 - Recommended Guidance For The Training Of Designated Unmanned Aerial Vehicle Operator (DUO) is the reference. It establishes a broad set of training guidelines and the skills required of a DUO to safely operate a UAV in all classes of airspace as well as to conduct precise and efficient response measures in emergency situations. In particular, it assumes that piloting a UAV system requires a skill set that approximates that of operating a manned aircraft. However, there are also some requirements specific to UAV systems, such as relying on synthetic presentations to develop situational awareness and managing the lack of physical influences such as G-forces.

5.4 Recommendations for integrating UAV with Air Traffic Management rules

5.4.1 Analysis of integration of UAV with Air Traffic management rules

ATM rules are defined in ICAO annex 2 [R4]. They have been developed for manned aircraft operation and by extension to all airspace users.

Airspace classes are defined at international level but existence of intermediate classes depends of countries. Typically, in Europe it exist ATC controlled airspace (class A to C) and uncontrolled airspace (class G). In the USA, intermediate classes E are much more widespread.

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Class	Type of flight	Separation provided	Service provided	Speed limitation	Radio comm. required	Subject to an ATC clearance
A	IFR	All aircraft	Air traffic control service	Not applicable	Continuously two-way	Yes
B	IFR					
	VFR					
C	IFR	IFR from IFR IFR from VFR				
	VFR	VFR from IFR	1) ATC service for separation from IFR; 2) VFR/VFR traffic information (+ traffic avoidance on request)	250 kts IAS below 3050 m (10.000 ft) AMSL		
D	IFR	IFR from IFR	ATC service, traffic information about VFR flights (+ traffic avoidance advice on request)			
	VFR	Nil	IFR/VFR and VFR/VFR traffic information (+ traffic avoidance advice on request)			
E	IFR	IFR from IFR	ATC service and, as far as practical, traffic information about VFR flights			
	VFR	Nil	Traffic information as far as practical		No	No
F	IFR	IFR from IFR as far as practical	Air traffic advisory service; flight information service		Continuously two-way	
	VFR	Nil	Flight information		No	
G	IFR	Nil			Continuously two-way	
	VFR	Nil			No	

Table 5 - ICAO airspace classification

Note: For IFR operation in Class G airspace, separation is not provided by ATC but is assured to the extent possible by requiring aircraft flying IFR to conform to different altitudes depending on heading.

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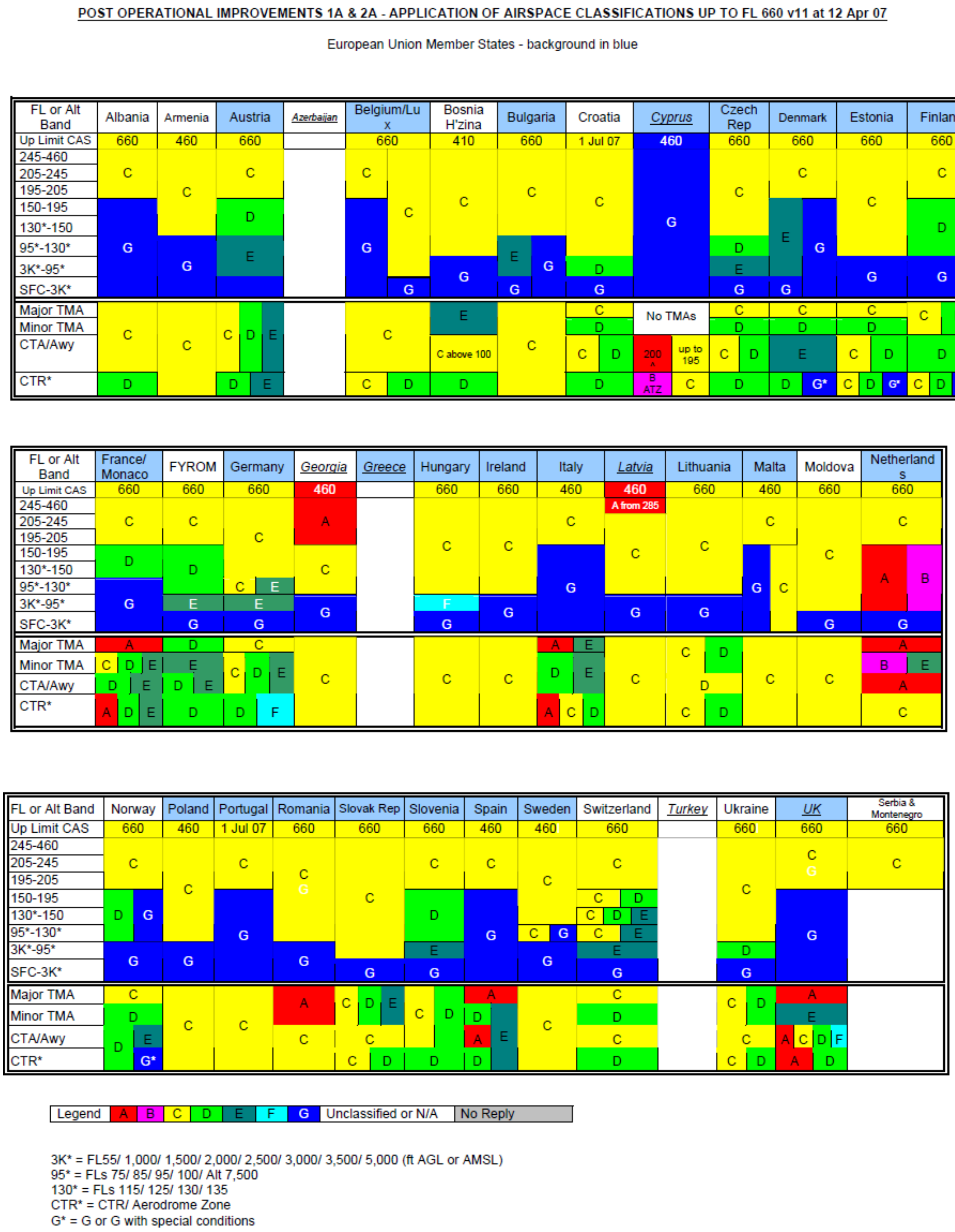

Figure 1 - European airspace classification 2007

CTA - Control Area. An area of controlled airspace extending upwards from specified limit above ground level (agl).

CTR - Control Zone. An area of controlled airspace extending upwards from ground level to a specified upper limit.

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For large UAV, air insertion, approach is different in Europe and in the USA.

In the USA, UAV shall be compliant with air rules. The RTCA DO-365 [R5] has been developed by USA. It states that remain welfare function coordinated with ATC is mandatory. However, collision avoidance function (such as TCAS, ACAS Xu) is optional.

In Europe, for large UAV, as intermediate classes almost doesn't exist, flight are ATC controlled. Only collision avoidance system shall be available. In case of altitude change not under controlled ATC, the remain welfare function shall be also required.

At short term, it is recommended to implement "smart segregation" used in France. That means having dynamically activated segregated airspace around the air vehicle. For regular flights, corridor should be defined to be activated by NOTAM when necessary.

At long term, a MOPS for EUDAAS in Europe should be written with associated technology for addressing collision avoidance function and remain welfare function. Two different use case (Male and tactical UAV) should be considered as solution should be quite different. Basis of this new EUDAAS should be the existing USA DO-365.

During the first live demonstration of the OCEAN2020 project, manned and unmanned vehicles were flying at the same time in the AOO, but each traffic had its own segregated area, and all operators had to fly within the designated area, according to a pre-fixed schedule and reporting any small deviation.

- Segregated zones for each UAV were identified within predefined flight zones which could be used for unmanned flights.
- Notice to Airmen (NOTAM) were elaborated and approved before the trial to accurately specify the air space zones for unmanned flights of each deployed UAV.
- Requests to activate NOTAM were submitted by the CTG to the Air Traffic Control Authority.
- The unmanned flights were authorized on approval of NOTAM request by the Air Traffic Control Authority, so that the UAV mission task order could be promulgated by the CTG.
- No Air Traffic Control services were made available by the Air Traffic Control Authority for unmanned flights, which remained under the responsibility of the remote pilot of each UAV, in particular the respect of the segregated flight zone specified by the NOTAM.
- The Air Traffic Control authorities broadcast orders to all civilian/military aircrafts in the air space forbidding the intrusion of manned flight into the segregated zones specified by the NOTAM for unmanned flights.
- The segregated zones specified by the NOTAM for unmanned flights were monitored by CTG staff to check that actually no civilian/military aircrafts were entering such zones.

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- Emergency procedures were established to interrupt any unmanned flight (giving immediate orders of Return to Base) in case of need to free the impacted flight zones for unexpected or emergency situations (including priority military flights).

Therefore, segregating the airspace was the way to comply with the Italian regulation regarding air traffic management. Moreover, SSR/ADS-B was not mandatory for the UAS “PELICANO” made available by INDRA, nor it was recommended by the authorities. The use of a transponder could have been a way to overview operations, besides an additional element able to increase situational awareness and safety.

5.4.2 Resulting recommendations for integrating UAV with Air Traffic Management rules

An analysis of the wide-discussed recommendations for integrating UAV with Air Traffic Management rules are summarised in the following recommendations:

Recommendation number	Recommendation description
D662-5.4-A	At short term, for safety and efficiency, it is recommended to implement “smart segregation” that means having dynamically activated segregated airspace around the air vehicle. For regular flights, corridor should be defined to be activated by NOTAM when necessary
D662-5.4-B	At long term, a MOPS for EUDAAS in Europe should be written with associated technology for addressing collision avoidance function and remain welfare function. Two different use case (Male and tactical UAV) should be considered. Basis of this new EUDAAS should be the existing USA DO-365.
D662-5.4-C	The use of a transponder should be a way to overview operations, besides an additional element able to increase situational awareness and safety.

5.5 Recommendations for the elaboration of EU Standards for the safety of UAV deployments

Two levels of recommendations have been identified. The first one concerns recommendation regarding development of the EU standard for safety of UAV deployments, and the second one concerns generic approach for classification of feared events.

5.5.1 Recommendations for EU Standards

In the previous sections it has be shown the state of the art of the regulations applicable to RPAS. It has been observed that it is a sector that has evolved very quickly taking advantage of

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both existing technologies and posing new technological challenges. In this phase of adaptation, the lack of some specific standards for UAVs has been evidenced. It has been solved mainly by adapting existing standards for manned aviation. This necessary adaptation has produced different approaches or interpretations of the requirements of both the industry and the authorities.

To try to fill these gaps, different work groups have appeared associated with different industries, organizations, associations, regulations authorities, etc. (JARUS, ICAO, ASD, ANSI, ISO, ETSI, EUROCAE, EASA, FAA, ...) that have started working on developing different standards or providing guidance related to the different challenges that have been addressed. In that sense, it could be advantageous that some supranational authority organizes the results of all these working groups, identify the more important and assumes the results in order to have a set of reference documentation for the certification authorities. From this point, the needs related to new standards development can be defined and identified.

The developments of standard for the safety of UAV deployments should take into account the characteristics related to the design of the system as well as the safety of the operation and address also aspects regarding the crew licensing, the use of frequencies and the use of airspace, in particular, the coexistence of UAVs with manned aircraft, allowing the extension of flight areas for UAVs. It should be a common approved approach to this issue in order to facilitate the UAV deployments.

5.5.2 Recommendations for Hazards Classifications/ Severity Classification

The objective of this chapter is to allow classification risk level regarding induced effect. The methodology is to:

- Takes definition of document already written by authority for hazard classification,
- Presents Risk Assessments (harm to people on ground, mid-collision, etc.),
- And then Classify Feared Events in each operation identified.

5.5.2.1 Hazards Classifications

Hazard classifications are used to determine the tolerability of risk that any safety case will be benchmarked against.

For the purpose of this analysis the hazard classifications will be taken from SC.RPAS.1309. These hazard classifications have been chosen to ensure continuity with current regulatory practice. It allows to classify functional effects.

SC.RPAS.1309 currently utilises the following hazard classifications outlined within Table 6. These hazard classifications have had minor textual amendments to replace RPAS, with UAS, to ensure consistency.

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Table 6 - RPAS 1309 Hazard classifications

Hazard Classification	Hazard Classification Description
No Safety Effect	Failure conditions that would have no effect on safety. For example, failure conditions that would not affect the operational capability of the UAS or increase the remote crew workload.
Minor	Failure conditions that would not significantly reduce UAS safety and that involve remote crew actions that are within their capabilities. Minor failure conditions may include a slight reduction in safety margins or functional capabilities, a slight increase in remote crew workload, such as flight plan changes.
Major	Failure conditions that would reduce the capability of the UAS or the ability of the remote crew to cope with adverse operating conditions to the extent that there would be a significant reduction in safety margins, functional capabilities or separation assurance. In addition, the failure condition has a significant increase in remote crew workload or impairs remote crew efficiency.
Hazardous	Failure conditions that would reduce the capability of the UAS or the ability of the remote crew to cope with adverse operating conditions to the extent that there would be the following: (i) Loss of the UA where it can be reasonably expected that a fatality will not occur, or (ii) A large reduction in safety margins or functional capabilities, or (iii) High workload such that the remote crew cannot be relied upon to perform their tasks accurately or completely.
Catastrophic	Failure conditions that could result in one or more fatalities.

5.5.2.2 *Risk Assessments*

Risks assessment of an UAS operation takes into account:

- Damage to critical infrastructure,
- Mid-air collision with manned aircraft, and
- Harm to people on the ground.

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The risk to critical infrastructures applies to large size UAS that, even if they do not crash on third parties on the ground, would cause prejudicial damages to any infrastructure linked to a State's economy, security, health and public safety.

Concerning the risk towards other airspace users, there is risk mitigation measures already adopted by various authorities to minimize the risk of operation. Those risk mitigation measures are most commonly for:

- Operation in visual line of sight (VLOS),
- Maximum height of operation set below minimum flight height for regular manned aviation operations, and
- Safety distance imposed regarding aerodromes.

The safety objective depends almost entirely on the risk to people on the ground if the risk mitigation measures towards other airspace users are implemented. This risk can be assessed by determining the probability of having a crash resulting in a fatality.

The victims could be participants who are directly or indirectly involved, or people not associated with the UAS operation.

Harm could result from a direct impact of the UAS, a component of the UAS, or its payload with people causing injury or death. This includes the harm resulting from post-crash explosion or fire. Harm could also result indirectly from the UAS. Both direct and indirect harm to people on the ground could be accidental or purposeful. However, the safety risk is only associated with accidental harm. The risk of purposeful (wilful) harm is considered a security risk.

5.5.2.3 Feared Events Classification

Feared events are functional effects at UAS level which could occur during the operation. Hazards classification of feared events depends on uses cases and operational mitigation implemented.

The typical use cases implying UAS within §3 for representing high level scenarios are listed below:

- Littoral Area Persistent Surveillance - Friendly Coast (with UAS, with USS, with UUS),
- Littoral Area Persistent Surveillance - Unfriendly Coast (with UAS, with USS),
- High Sea Persistent Surveillance (with UAS, with USS),
- Foreign and Home Naval Base Protection (with UAS, with USS, with UUS),
- Choke Point Transit Surveillance (with UAS, with USS, with UUS),
- Mine Counter Measures Support (with UAS, with USS, with UUS),
- Support RHIB Boarding (with UAS),
- Support Manned Helo Boarding (with UAS),
- Support Interception - Self Defense (with UAS),

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- Support Interception - Manned Helo (with UAS) (with or without hard kill engagement),
- Support SSM Engagement (with UAS),
- Engage Threat (with UAS, with USS),
- Support NFS (Naval Firing Support) (with UAS),
- Riverine Surveillance (with UAS),
- Sea Pollution Control (with UAS and USS).

It can be sum up in 4 operation areas:

- Littoral operation,
- High sea operation,
- Harbour/Naval base operation,
- Landscape operation.

§5.5.2.5 presents generic feared events in each operation case.

5.5.2.4 *Operational Mitigations*

Restricting the use of UAS from over or near people limits the likelihood of these people being injured in case of an accident. The appropriateness and necessity of the limitation depends on:

- The safety distance to people to be respected,
- The maximum number of persons (group of people or population density) above which an UAS can be used,
- As well as limiting the characteristics of the considered UAS.

A UAV crash in a high population density area (city, harbour, etc.) should be considered as Catastrophic since the probability to lead to fatalities is high. However, a crash in a low or a no density population zone (such as seaside) shall be considered as Hazardous. In that zone, it is reasonably expected that a fatality will not occur (refer to Table 6 for classification).

In order to reduce safety risk, UAS have to implement function to reduce ground risk by:

- Measures protecting non active-participants,
- Reducing the effect of the UAV impact dynamics (area, energy, impulse, transfer energy (parachute, etc.)),
- Measures to reduce the number of people at risk
  - Emergency Response Plan (ERP). The ERP is expected to cover the plan proposed by the applicant to limit crash escalating effect (e.g. notify first responders …) and the conditions to alert ATM.
  - Emergency Recovery Strategy proposed by the applicant.

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- Procedure that is implemented through UAV crew command or through autonomous design means in order to mitigate the effects of critical failures with the intent of minimising the risk to third parties. This may include automatic pre-programmed course of action to reach a predefined and unpopulated forced landing or recovery area.
- In case of emergency landing, it is expected:
  - UAV is still controllable and can follow flight plan,
  - UAS alert ATM / UTM of the situation in order to minimize safety risk with other UxS and Airspace users.

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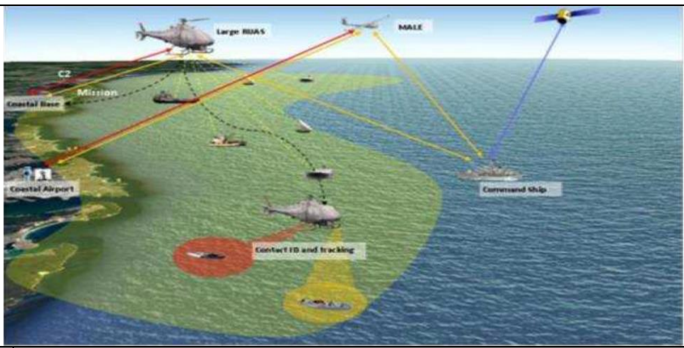
5.5.2.5 *Fearing Events according to OCEAN2020 operation areas*

Feared events listed in the tables below concern only UAS events. Combination of UAS and others system failures are not taken into account.

Table 7 - Littoral Area Feared Events



Hazard Classification	Feared Events
Catastrophic	Crash/Collision on Vessel
	Collision with manned Aircraft (Mid-Air Collision)
	Uncontrolled crash
Hazardous	Crash/Collision with others UxS
	Leaving operating area / Fly Away
	Total or partial loss of UAV airframe
	Emergency Landing
Major	Contingency Landing
	Loss of control of operation, Loss of the ability to operate during the mission.
	Loss of the ability to locate the UAV by the operator
	Loss of the ability to alert
Minor	Trajectory conflict with others aircraft
No Safety Effect	-

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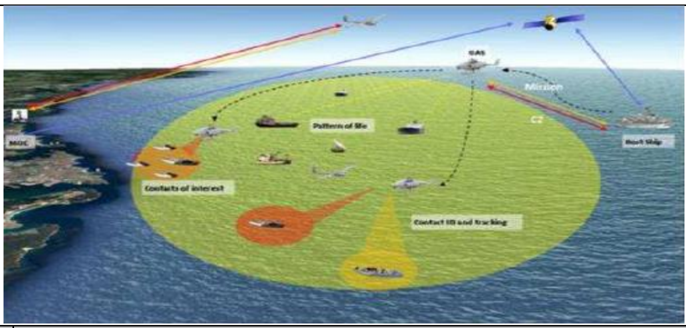
Table 8 - High Sea Area Feared Events



Hazard Classification	Feared Events
Catastrophic	Crash/Collision on Vessel
	Collision with manned Aircraft (Mid-Air Collision)
Hazardous	Uncontrolled crash
	Crash/Collision with others UxS
	Leaving operating area / Fly Away
	Total or partial loss of UAV airframe
Major	Emergency / Contingency Landing
	Loss of control of operation, Loss of the ability to operate during the mission.
	Loss of the ability to locate the UAV by the operator
	Loss of the ability to alert
Minor	Trajectory conflict with others aircraft
No Safety Effect	-

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Table 9 - Harbour/naval base Area Feared Events

Hazard Classification	Feared Events
Catastrophic	Crash/Collision on Vessel
	Collision with manned Aircraft (Mid-Air Collision)
	Uncontrolled crash
	Leaving operating area / Fly Away
	Total or partial loss of UAV airframe
Hazardous	Crash/Collision with others UxS
	Emergency landing
Major	Contingency Landing
	Loss of control of operation, Loss of the ability to operate during the mission.
	Loss of the ability to locate the UAV by the operator
	Loss of the ability to alert
Minor	Trajectory conflict with others aircraft
No Safety Effect	-

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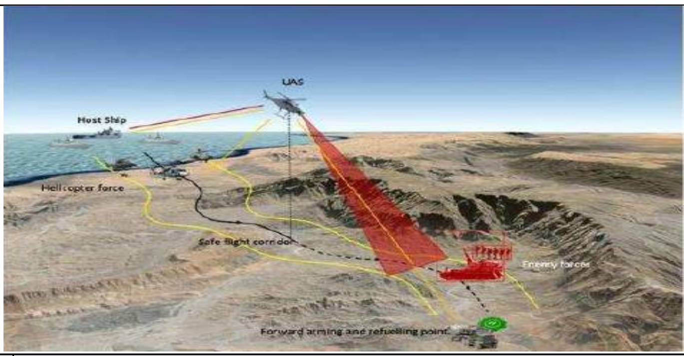
Table 10 - Landscape Area Feared Events



Hazard Classification	Feared Events
Catastrophic	Crash/Collision on Vessel
	Collision with manned Aircraft (Mid-Air Collision)
	Uncontrolled crash
	Leaving operating area / Fly Away
	Total or partial loss of UAV airframe
Hazardous	Crash/Collision with others UxS
	Emergency Landing
Major	Contingency Landing
	Loss of control of operation, Loss of the ability to operate during the mission.
	Loss of the ability to locate the UAV by the operator
	Loss of the ability to alert
Minor	Trajectory conflict with others aircraft
No Safety Effect	-

5.5.3 Resulting recommendations for the elaboration of EU Standards for the safety of UAV deployments

An analysis of the wide-discussed recommendations for the elaboration of EU Standards for the safety of UAV deployments are summarised in the following recommendations:

Recommendation number	Recommendation description
D662-5.5-A	Supranational authority should organize the results of all working groups on different standards or providing guidance for UAVs, identify the more important and assumes the results in order to have a set of reference documentation for the certification authorities.

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Recommendation number	Recommendation description
D662-5.5-B	The developments of standard for the safety of UAV deployments should take into account the characteristics related to the design of the system as well as the safety of the operation and address also aspects regarding the crew licensing, the use of frequencies and the use of airspace, in particular, the coexistence of UAVs with manned aircraft, allowing the extension of flight areas for UAVs.
D662-5.5-C	Table 6 provides hazards classification that shall be used for safety analysis.
D662-5.5-D	In order to reduce safety risk, UAS have to implement function to reduce ground risk by: ▪ Measures protecting non active-participants, ▪ Reducing the effect of the UAV impact dynamics (area, energy, impulse, transfer energy (parachute, etc.)), ▪ Measures to reduce the number of people at risk o The Emergency Response Plan is expected to cover the plan proposed by the applicant to limit crash-escalating effect (e.g. notify first responders …) and the conditions to alert ATM. o Emergency Recovery Strategy proposed by the applicant. ▪ Procedure that is implemented through UAV crew command or through autonomous design means in order to mitigate the effects of critical failures with the intent of minimising the risk to third parties. This may include automatic pre-programmed course of action to reach a predefined and unpopulated forced landing or recovery area. ▪ In case of emergency landing, it is expected: o UAV is still controllable and can follow flight plan, o UAS alert ATM / UTM of the situation in order to minimize safety risk with other UxS and Airspace users.

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6 RECOMMENDATIONS FOR SITUATION AWARENESS STANDARDIZATION

6.1 Methodology

The analysis will be built according to a four-step methodology summarised in Figure 2.

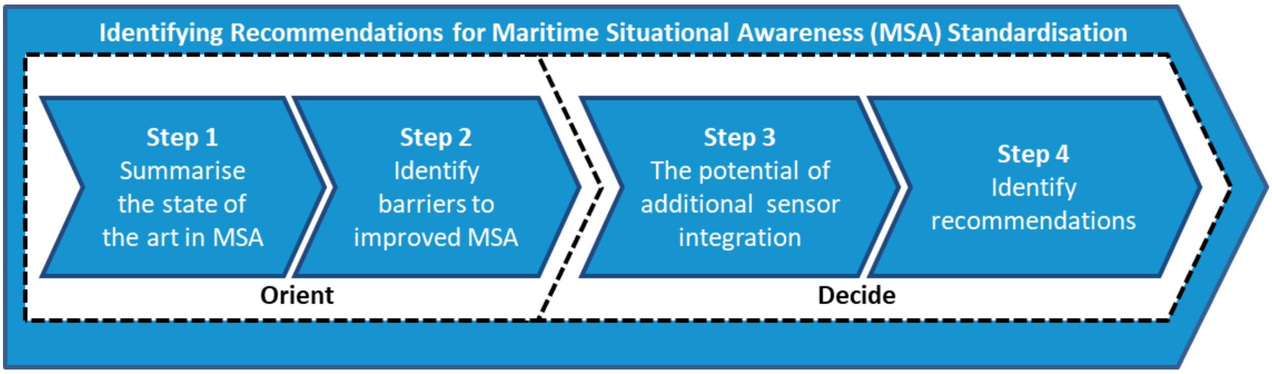

Figure 2 - Overview of the process to identify MSA recommendations

First, the current methods to obtain MSA in Europe will be synthetized from an extensive review of the existing official documents and literature on the topic. The information gathered will be substantially complemented by interviews with personnel from the participating Navies, with a particular focus on those that actively participate in the Sea Demonstrations. Such activities will produce the first part of the analysis focused on the MSA state of the art in Europe.

The second step will highlight the main obstacles to the achievement of a comprehensive MSA through the methods currently used. In this framework, the limitations deriving from both the use of conventional systems and the current application of UxVs will be taken into account. As for the previous point, there will be joint use of interviews and official documents/dedicated literature. Such work will elaborate the second part of the analysis, devoted to current obstacles, problems and limitations to a comprehensive MSA.

The first two parts of the report are intended as a general overview on the state of the art and challenges currently faced in the obtainment of MSA. Building on such a basis, the deliverable's third step will then address the potential future developments related to the integration of UxVs with manned platforms and to the integration of UAV with Satellite Data. In order to provide a more policy-oriented and thought-provoking analysis, the challenges that could arise in this process will be also singled out.
Accordingly, on the one hand the analysis will focus on both the added value and obstacles brought by a deeper and better integration of unmanned platforms with manned assets. On the other hand, the potential benefits and problems connected to the integration of UAV and Satellite Data will be discussed. With a particular regard to problems, the analysis will primarily focus on technical, operational and legal/regulatory barriers, as well as to the lack of

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standardized procedures. With reference to the legal/regulatory barriers, the analysis will focus at EU level.
In this context, the feedbacks and lessons learned derived from the Sea Demonstrations will be considered with respect to UxV integration's added value and obstacles, including technical, operational and legal/regulatory barriers.

The fourth and last step will be dedicated to the provision of recommendations for improving the standardisation in MSA. Such recommendations will draw from the previous three steps, and will particularly target the challenges of unmanned-manned integration as well as UAV and Satellite Data integration. In this context, proposals may regard both policy and procedures, according to the previous analysis.

6.2 Recommendations to improve situational awareness policy in naval environment by use of Unmanned Systems

6.2.1 State of the art and limits of the Maritime Situational Awareness

The European Union defines MSA as the effective understanding of activities associated with- and occurring in the maritime domain that could impact on the security, safety and environment of the EU and its Member States. In more general terms, MSA is the perception and meaningful comprehension of the elements in the maritime environment within specific spatial and temporal coordinates, their nature, and the projection of their status in the near future. Therefore, for achieving a comprehensive MSA, it is necessary to collect intelligence information on the "pattern of life" that characterises "normal" activities and behaviours of ships and harbours operating in an area of interest (AOI) over a long period of time. Indeed, only by having a clear picture of what is normal it is possible to recognise what is "abnormal" and potentially threatening.

An effective MSA can only be achieved by integrating a large amount of data gathered from multiple sources that range from spatial intelligence (i.e. through satellite data) to naval units deployed in a certain area (i.e. through data received from radar, EO/IR sensors, etc.). Furthermore, a high degree of computational capabilities is needed for systematising and elaborating these data. The refined information will then be distributed via dedicated, reliable, and secure channels.

Since relying on effective MSA capabilities is crucial to both the military and civilian domains, and it is of interest for every country and stakeholder with interests in the maritime domain (from trade, to national and international security), many initiatives have been launched with the aim of improving this capacity on a cooperative basis.

These collaborative efforts are mostly dealing with the collection and distribution of intelligence data from satellites, and they are intended for providing coherent and effective Vessel Traffic Service (VTS). One of the most effective examples is represented by the Collaborative Space-based Maritime Situational Awareness (CSMSA) network, which envisages

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a global collaboration of all space-faring nations linking together existing and planned unclassified space system capabilities to form a worldwide collaborative network.

Earth observation satellites provide many data that can be used for gaining a near real time (NRT) situational view at operational level. Satellite images can be automatically processed in order to detect and identify vessels with no substantial time loss, thus generating information useful for further actions.

Many satellite-based elements that employ passive sensors should be integrated for achieving effective results. Among these, the most relevant are:

- Automatic Information System (AIS), globally used as a primary ship identification system. The AIS Satellites collect the information provided by AIS sensors and transponders installed on almost every ship. These data include identification, position, course, and cargo information. AIS is considered as one of the key components of the process behind the achievement of a global MSA. AIS signals can be sent and received also through Very High Frequency (VHF) radio waves.
- Unclassified Signals Intelligence Satellites (SIGINTSats);
- Long Range Identification and Tracking (LRIT) satellites that collect information from all those ships obliged by International Maritime Organization (IMO) regulations to carry a transponder for these data;
- Vessel Monitoring Systems (VMS) exploit the data provided to satellites by on-board transponders;
- Synthetic Aperture Radar Satellites (SARsat) that allow the acquisition of data at any time of day or night and independent of cloud coverage, collecting both amplitude and phase data. SAR images are, therefore, suited for providing situational data during an operation, especially if far from the national waters or out of the coverage of the traditional monitoring legacy systems.
- Electro-optical (EO) imaging satellites which operate in the visible or near-visible portion of the electromagnetic spectrum (EM);
- Video Optical Satellites;
- Machine-to-machine (M2M) communication satellites based on individual transponders sending short formatted status reports to communications satellites.

Satellite systems are among those platforms that are considered able to provide "observables", namely data describing the situation which is being monitored. Indeed, by fusing AIS data, the information extracted from the satellite images, as well as any other available information, it is possible to detect all targets in the monitored area, including those that do not transmit AIS signals (the so-called "dark vessels"). This implies a remarkable enhancement of MSA quality, therefore reaching information superiority. Indeed, the

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vessel/ship detection capability can be used to automatically detect anomalous behaviours in the surveyed area. In addition to dark vessels, examples of anomalous behaviour are, for instance, finding a vessel in a restricted area, or having a vessel travelling at a velocity above a certain threshold. Once similar anomalies are identified, it is possible to use them for drafting reports and sending alerts. By systematically acquiring satellite images over an identified AOI, it is then possible to obtain NRT information concerning possible anomalies in a vessel's behaviour.

Besides satellites, there are ground-based infrastructures responsible for tasking the satellites and analysing the data provided, combining them with information from other sources. These are:

- The ground infrastructure, terminals, software tools and licenses that allow system users to determine which spacecraft should be tasked for obtaining the desired results.
- The software used for correlating, fusing, and analysing the information generated by the space systems including the AIS data, along with all other pertinent data made available by other sources, such as ports and shipping and broker records.

Lastly, a further contribution to the achievement of effective MSA on a collaborative basis is offered by:

- Data made available by a set of different entities, such as international organisations, national authorities, private companies, and single ships. These data can include information from patrolling vessels as well as from leisure boats.

Other specific information provided by states participating in international fora.

In recent years, international organisations (such as the European Maritime Safety Agency – EMSA), states, and harbours authorities have started to support financially or to put in service Unmanned vehicles (UxVs) — most notably Unmanned Aerial Vehicles (UAVs) — for increasing their ability to acquire MSA. UxVs equipped with EO/IR cameras and a multitude of other instruments such as radars, sonars, radio detectors and AIS sensors can substantially complement data provided by other sources.

A relevant achievement made possible through the use of UxVs is the reduction of operational costs and the potential guarantee of a 24/7 operational coverage. Such a coverage, which has the further advantage of almost eliminating operational risks to personnel involved, can be ensured by the deployment of multiple UxVs. Despite the potential benefits deriving from further use of UxVs for acquiring MSA and the fact that the technology associated to these assets is growing at a swift pace, their practical deployment is still minimal.

All the information gathered through the data provided by the aforementioned satellites, the information exchange through more traditional methods such as the sharing of relevant data

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by international and national organisations, and UxVs intelligence activities, are accessible. In addition, they are of the utmost importance for appropriately understanding the normal pattern of life in AOI, which can be both in the open sea or in the proximity of a littoral zone. However, this information may still not be sufficient for recognising threatening behaviour or confirming the nature of a potential contact of interest in military or law enforcement operations. Indeed, even the most important instrument for ships identification, namely the AIS, may not be capable of providing relevant information, since these signals can be deliberately disturbed or blocked through spoofing activities.

Therefore, data provided by other sources at a single ship level must be made available and integrated for complementing the openly accessible intelligence information gathered through the aforementioned instruments and methods. Only by implementing such integration it would be possible to acquire a complete Recognised Maritime Picture (RMP), which is crucial for any military mission that has to be performed in any maritime area of operation (AOO). Even in the event satellite-based instruments do not recognise the presence of a ship in a AOO — either because of a deliberate spoofing of AIS signals or because the contact is a small ship that does not carry any AIS transponder — it would still be possible to detect its presence through different on-board instruments.

Among the many instruments currently used for achieving an MSA as comprehensive as possible through sensors carried by single naval units. Among these, the most relevant are:

- Local weather and visibility sensors;
- Radars (also in SAR configuration);
- EO sensors and camera for the visible range and in day-light conditions;
- IR sensors and camera that can provide data also in night operations;
- Sonar sensors.

Moreover, military vessels are usually equipped with additional Electronic Support Measures (ESM) that can enhance the performances of other instruments such as Radars (R-ESM) or communication tools (C-ESM).

The role of the ships deployed in the area is of paramount importance for acquiring a complete RMP. Indeed, thanks to the assets present in the AOO, it is possible to raise awareness on the presence of ships, vessels, small boats or other platforms that can be hostile, thus representing a direct threat or conduct illicit activities of various natures. Thanks to the radars installed on the military vessels, it is possible to detect and locate ships that present a certain cross-radar section. In addition, EO cameras allow the acquisition of visual imagery on the potential contact of interest in daylight conditions and within a certain range. In order to complement EO sensors and camera’s capabilities, their IR counterparts provide similar possibilities in night operations; yet, these sensors are also limited by a certain range of operation. Lastly, the sonars can detect the presence of a moving boat based on the sounds it emits.

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Based on previous intelligence activities, the vessels present in the area can add their information to those already provided. This way, they are able to recognise if, and when, an abnormal activity is present within the AOO.

The combination of data provided by satellite-based instruments, UxVs, and sensors installed on the ships present in, or in the proximity of, an AOO represents the method through which MSA is currently obtained. However, it should be noticed that small ships with a minimal cross radar section — often used by irregular militias, terrorist and organised crime groups, and pirates — may be difficult to spot through radars. Should they be operating outside of the EO/IR sensors coverage, these difficulties consistently increase.

In addition to that, the data provided are often not sufficient for conducting efficient identification and classification activities.

Indeed, even if the presence of a potentially threatening contact is recognised by on-board instruments and confirmed by satellite intelligence data, in many cases it is not possible to clearly label it as an actual threat or a hostile contact, nor to assess the most appropriate procedures to engage it. Regarding this latter aspect, it is important to mention that the ROE of every military operation performed by European countries both at a unilateral and multilateral level, or conducted within the framework provided by the EU, requires a very high degree of certainty before allowing engagement. This certainty can only be achieved through direct observations and permanent monitoring of the contact of interest. In order to fulfil these tasks, manned platforms such as helicopters are currently used. However, the use of these assets does not allow a permanent monitoring due to the refuelling needs and the personnel shift. Moreover, the costs associated to the continuous use of manned platforms are so high that their use cannot be considered as cost-effective. For all these reasons, further integration of UxVs with manned assets can represent a substantial added value.

As a general consideration, it can be notice how the strengths of one system can balance the weakness of the other. Table 11 reports the most prominent characteristic for satellite and UAVs:

Table 11 - Prominent characteristic for satellite and UAVs

Characteristics	
Area Coverage	Better for satellites
Resolution (e.g. atmospheric effects on resolution)	Better for UxV
Availability (when and where required)	Better for UxV
Flexibility (to change mission parameters, type of payload, …)	Better for UxV
Real Time (direct use of data and response time of the system)	Better for UxV
“Pre-conflict” data availability	Better for satellites

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Characteristics	
Maintainability and upgrade of the system and payload	Better for UxV
Data/Service Cost to Users (*)	Better for satellites
Heterogeneity of quality for the same service	Better for satellites

Source: Indra and MDA presentation (Satellite and UAV cooperative missions: status and outlook) ESTEC (Noordwijk)

(*): the cost for the considered satellite service excludes any cost of satellite development, launch and desorbitation.

6.2.2 Added value of UxVs in the performance of MSA

UxV platforms provide added value to the situational awareness in naval environments, thanks to new capacities with which they are able to complement manned platforms, and because they are able to gather information for a long time period over a given AOO. In particular, this integration is beneficial to three key areas:

- Environmental situational awareness from the perspective of operators and vehicles;
- Vehicle status situational awareness from the perspective of the operator;
- Through-the-sensor situational awareness of mission progression from the perspective of the autonomous vehicle.

They also facilitate the use of specific sensors which are adequate to the kind of information needed, thus enhancing searching capabilities. Furthermore, UxVs can act as communication relay platforms able to coordinate different resources. They offer better endurance than manned platforms, and can operate in more adverse conditions, while also reducing the costs of operation. In addition, UxV do not put any crew lives at risk, neither the platform crew, nor the Search and Rescue (SAR) team that could be deployed in specific cases (i.e. an aircraft crash).

In general, the integration of different kinds of platforms allows the whole system to extend its capabilities. In order to gain a better understanding of the implications of such integration process, one could consider the following examples:

- An autonomous system allows the operator to focus on different tasks or to supervise different sensors at the same time.
- The combined use of manned and unmanned platforms allows the selection of the one that is more feasible for operating in different conditions, such as:

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  - use of airspace (where unmanned operations are not allowed and it is therefore required to have manned platforms);
  - operations that occur in specific weather conditions, are performed at night, or that require a high persistence – all of these may, indeed, necessitate an unmanned platform.
- An autonomous system can provide a great amount of data, while manned platforms allows a more detailed analysis of the collected information.
- Unmanned and manned platforms can also perform real-time operation and cooperation (manned and unmanned teaming, MUT), which allows a high capacity to obtain information.

In the Mediterranean Sea live demonstration, multi-domain UxVs where employed to extend the surveillance capabilities of a naval Task Group, providing near real time videos and tracks of targets seen with their sensors (beyond the range of mother ships sensors), both on the sea surface and underwater (dummy mines laying on the sea bed). Near real time videos and tracks, as well as processed sonar images, provided by the unmanned systems were shared among different naval units at sea and several Maritime Operation Centres (MOC) on land, improving situational awareness.

With a specific regard to the UUS platforms, and the potential benefits deriving from a further integration of these platforms with manned assets, it should be noticed how the advent of new underwater technologies has allowed situational awareness to transit from ship-based to distributed, networking capabilities. This networking paradigm assumes that the most effective and efficient approach to monitor the elements in the marine environment is through a spatially-distributed fleet of robotic platforms.

An environmental assessment or environmental situational awareness is vitally important in both the planning and execution stages of a mission, as the underwater environment is challenging, diverse, and fluctuates over time. Due to their endurance, robustness and maneuverability, underwater gliders have played a significant role in providing environment situational awareness data via a networking paradigm. Gliders are buoyancy-driven autonomous underwater vehicles that take advantage of their hydrodynamic shape, wings and buoyancy changes to move between the surface and the ocean interior with a net horizontal displacement. Each glider can host multiple sensors including CTDs, dissolved oxygen sensors, sensors for backscatter and fluorescence, Photo-synthetically Available Radiation (PAR) sensors, echo sounder, passive acoustic monitoring (PAM) sensors, and ADCPs/DVLs for current measurements and biogeochemical sensors (nitrate, acidity and carbon dioxide levels).

The data collected by underwater gliders significantly contributed to the comprehension of the ocean environment, and helped projecting its status into the near future, leveraging its variability. The collection of environmental data is highly dependent on the requirements of the warfare application and mission and, as such, it is recommended to analyse the data

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requirements in the first instance. The applicability of using unmanned systems to collect data as well as the use of environmental data by unmanned systems should therefore be defined before initiating the collection process.

As part of the OCEAN2020 program, the CMRE Modelling and Simulation (M&S) team developed and tested a framework that allows the wide-scale environmental data from each domain — air, surface and underwater —to be collated and loaded into virtual models. This environmental data, partly collected by UxV systems, was provided via an on-line distributed simulation capability, to support the execution of project specific scenarios in the 1st Simulated Trial, allowing the concept of environmental situational awareness to be demonstrated and explored.

In addition, CMRE has been working on increasing operator awareness of the vehicle status and mission evaluation throughout its execution. The amount of information that can be sent by the underwater vehicle is limited by the underwater communications reliability, bit rate and latency. However, CMRE has worked under the OCEAN2020 program to provide live vehicle positions, detected target positions and vehicle status updates whilst the vehicle is underwater. With the support of modelling and simulation, mine-countermeasure scenarios were demonstrated, with data streams transmitted via underwater acoustic communication systems to surface relay buoys. In addition to 'in mission' evaluations, further activities have allowed surfaced UUVs to immediately send small images of the detected targets to higher level C2 nodes, enabling the rapid re-tasking or deployment of supporting assets if necessary. A summary of the in-mission situational awareness display obtained from the CMRE systems can be seen in Figure 3.

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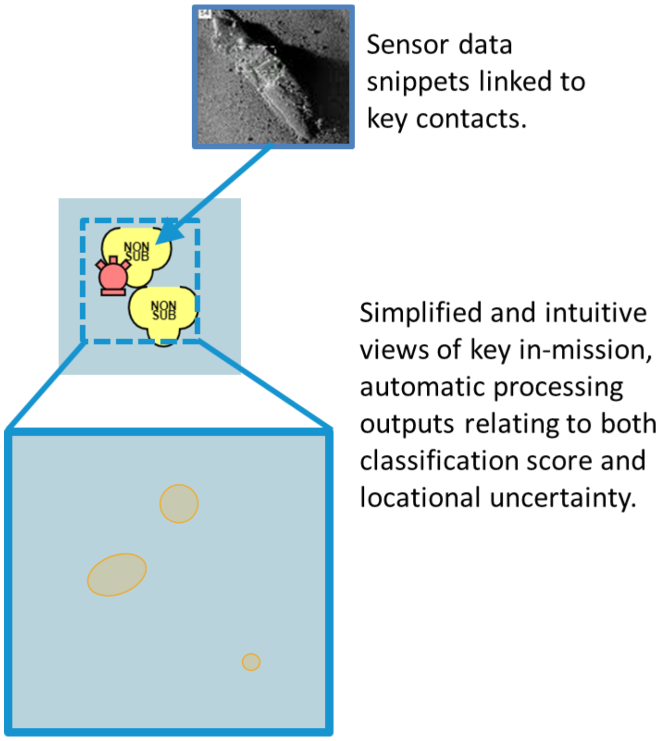

Figure 3 - Example situational awareness view produced by in-mission underwater assets

The added value of UAVs in the performance of situational awareness operations is manifold. First of all, the employment of UAVs allows a 24/7 coverage of the interested area. Secondly, UAVs are less visible than manned aerial assets, thus generating a situational advantage of the operators involved in the mission. Moreover, a UAV can be provided with a range of different payloads that can expand the area to be covered and controlled. Nonetheless, there are a set of aspects that need to be improved to efficiently and totally integrate manned and unmanned assets in the performance of MSA.

6.2.3 Legal and regulatory obstacles to improved MSA

Despite the potential benefits presented and the technical issues to be solved, there are still many barriers to overcome for allowing a proper integration of unmanned platforms with manned assets. Some of these challenges are specifically related to the regulatory and legislative frameworks.

Currently, EASA's Certification Specifications CS-ACNS are among the regulations governing the civil European procedures related to manned aviation aiming to comply with requirements associated to on-board Communications, Navigation and Surveillance Systems. In addition, military standards as MIL-STD-188 also define communications technical standards.

For the operation of both manned and unmanned platforms, and with the ultimate aim of ensuring safety, existing regulations impose technical requirements on platforms (certification, air/seaworthiness, equipment) that are related to both the use of air or maritime

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space and the qualifications of crews appointed at carrying out the operation. Yet, while manned platforms' design and operation are adapted to existing regulations, unmanned platforms of relatively recent appearance still have to adapt to them whilst making sure to offer new capabilities without affecting existing ones.

In a maritime environment, since ships can navigate all over the world, international unified regulations addressing both manned and unmanned operations and their integration are essential, not only for the performance of the operation itself, but also for the achievement of an enhanced situational awareness.

The regulatory aspects to take into consideration address administrative, technological and operational problems related to the integration of UxVs with manned platforms.

With regard to administrative aspects, three main issues can be identified.

- Firstly, a European framework for both standards and regulations is still under development. The lack of such a framework depends on the fact that design and operational procedures for unmanned assets differ from those involving manned operations.
- A second aspect that needs to be further explored is the liability attribution in case of an accident, being it in the form of insurances or in other formats.
- Lastly, a crucial issue to be addressed consists in the proper management of personal data and their privacy that may be gathered during a MSA operation.

Coming to regulations related to technical aspects for the UxV operation, the following ones need to be taken into account before an operation with unmanned assets can be deployed. With regard to the Registration, Certification and Maintenance of the unmanned platform, it is important to outline a clear set of requirements. In addition to having the appropriate air/seaworthiness certifications, unmanned platforms need to comply with Situational awareness and Detect and Avoid systems requirements. Moreover, a certain level of data link performance, as well as a proper use of the radio-electric spectrum, radar, GPS systems and AIS have to be assured. For a more detailed presentation of the policies to be implemented for the deployment of UxVs in military operations, please refer to section 4 of this document.

Overall, the solution of all the regulatory obstacles just presented must set out a flexible framework able of allowing technical and operational requirements of the manned and unmanned platforms integration to accommodate and evolve.

6.2.4 Recommendations for Situational awareness standardisation

The integration of UxVs in the European air and maritime space is a challenge for the future, and will also affect the way situational awareness operations are carried out. As a common consideration for all types of UxVs, it seems like their further exploitation in MSA operations is dependent on safety considerations. Furthermore, as a follow-up to this analysis, a set of

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recommendations has been identified and grouped around the identified areas of environments, vehicle states and mission progression situational awareness:

- *Environmental situational awareness* - It is recommended that a policy seeks to address future data management services that allow the timely management and distribution of larger and more complete environmental data sets. Nonetheless, for the time being, the collection of environmental data is highly dependent on the requirements of the warfare application and mission and, as such, it is recommended data requirements are analysed as a very first step. The applicability of using unmanned systems to collect data has to be investigated, as well as the use of environmental data by unmanned systems. In particular, interoperability among the systems should be ensured, in order to achieve a common and synchronised MSA among different countries. This requirement should tackle not only the information system, but also data link standards for UxVs. For security and certification reasons, each system is currently only managed by a single unit, and evolves in a segregated space. Moreover, the challenge consisting in the standardisation of the payloads exchanges and in the transfer of useful data to nearby units as RVT should be properly addressed, avoiding the transfer of non-relevant data which may cause an overload of the bandwidth.

- *Vehicle status situational awareness* - A policy should capture the requirements of operators in terms of the type of data, the frequency as a function of mission type and environment. Such policy should define the necessary types of communication means and recommend ways to improve communication in an operational context. This can be achieved by adapting existing capacities and working on existing problems such as integrity, latency or reliability of communications to perform C2 tasks, lack of redundancy, coverage or bandwidth developing a new architecture with dedicated equipment that improves the present capabilities (emergency situations, link loss, etc.). A further recommendation pertains the capacity of the unmanned system to reply to cyber-attacks. In other words, the system's resilience, the security of data, and the security of communication lines need to be ensured.

- *Through-the-sensor situational awareness of mission progression* - It is recommended that a policy seeks to address future requirements related to autonomy and artificial intelligence. Continuous development of more advanced collision avoidance (CAS) and identification (IFF) systems and their integration in more capable UxSs should facilitate their integration with manned aspects. Indeed, at the moment, the level of trust between manned and unmanned assets is not sufficient to grant their deployment together with other assets. Therefore, these requirements should also consider the possibility of UxVs employment in cooperative situations.

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6.2.5 Resulting recommendations to improve situational awareness policy in naval environment by use of Unmanned Systems

An analysis of the wide-discussed recommendations to improve situational awareness policy in naval environment by use of Unmanned Systems are summarised in the following recommendations:

Recommendation number	Recommendation description
D662-6.2-A	For effectiveness, Maritime Situation Awareness shall integrate large amount of data from multiple sources: • AIS, • unclassified signal intelligence satellite, • synthetic aperture RADAR satellite, • electro-optical imaging satellite, • video optical satellite; • UxVs equipped with EO/IR cameras, RADAR, SONAR, ESM, AIS sensor • vessels equipped with sensors.
D662-6.2-B	For effectiveness and cost advantage, use of UxVs is recommended for potential guarantee of a 24/7 operational coverage
D662-6.2-C	To get underwater environmental situation awareness it is recommended to use UUV equipped with several sensors amongst: • CTDs, • dissolved oxygen sensors, • sensors for backscatter and fluorescence, • phot-synthetically available radiation sensors, • echo sounder, • passive acoustic monitoring sensors, • ACPs/DVLs, • biogeochemical sensors (nitrate, acidity and carbon dioxide levels)
D662-6.2-D	For the efficient environmental situation awareness, it is recommended : • that a policy seeks to address future data management services that allow the timely management and distribution of larger and more complete environmental data sets • for the time being, data requirements shall be analysed as a very first step • to investigate use of UxVs to collect data

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Recommendation number	Recommendation description
	• to ensure interoperability among information systems and data link standards for UxVs • to address standardization of the payloads exchanges and the of useful data to nearby units
D662-6.2-E	For the vehicle status situation awareness, it is recommended : • that a policy should capture the requirements of operators in terms of the type of data, the frequency as a function of mission type and environment • that the system's resilience, the security of data, and the security of communication lines need to be ensured
D662-6.2-F	For the through-the-sensor situational awareness of mission progression, it is recommended : • that a policy seeks to address future requirements related to autonomy and artificial intelligence • to continue development of more advanced collision avoidance (CAS) and identification (IFF) systems and their integration in more capable UxSs • to consider the possibility of UxVs employment in cooperative situations

6.3 Recommendations for the elaboration of procedures to integrate UAV and Satellite data

Recommendations to improve MSA policy with the integration of UAV and Satellite data are discussed and identified in the following section.

6.3.1 The potential of integrating UAVs and Satellite data

The integration of UAVs with satellite data will bring numerous benefits, the most relevant of which concerns the opportunity to task a UAV to conduct a mission in an automatic manner. By resorting to the satellite-obtained data and the duly generated alerts, the unmanned system can be tasked to investigate events or vessels that might be detected. The tasking of a UAV can happen in one of the following ways:

- By human intervention — an operator assesses and verifies the alert that was received and, based on this information, tasks the UAV to conduct the operation;

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- In Automatic mode – if there is a well-defined API, the satellite processing service can use that to integrate the UAV mission planning system.

In addition, the operational adoption of satellite monitoring in the acquisition of a MSA permits the achievement of a new set of information and actions. In particular the use of satellite monitoring allows to:

1) Obtain further CNS services. Thanks to their mobility, reliability, jam-resistant communication and high data rate, satellites are able to benefit UAVs with video communications or other image sensors for tasks that are critical to a given mission's success.
2) Extend the coverage limit of traditional monitoring systems (e.g. coastal radar, terrestrial AIS). Indeed, satellite systems allow UAVs' C2 communications to go BVLOS, providing a wide coverage range.
3) Optimise the exploitation of traditional patrolling assets to be deployed after the detection of anomalies from the satellite monitoring.

Lastly, the integration of satellites and UxVs can substantially complement the efforts made for acquiring in-depth MSA. In particular, satellites and UxVs can collaborate in order to mutually extend their capabilities under various circumstances:

- Within a certain space segment, satellites data can support UxVs — and especially UAVs — through the provision of assistance for the UAS navigation and surveillance. Moreover, they can act as a relay for operational communications Beyond Visual Line of Sight (BVLOS) with command and control, ATC, etc. Satellites are also useful for collecting, storing, and transmitting data collected by UAV payload (BVLOS).
- Outside of a given space segment, UxVs and satellites are complementary. The information gathered separately by satellites can be merged for effective satellite-UAV collaboration; in addition, UxVs are able to gather information in areas with no coverage from the space segment. As a matter of fact, from an operational point of view, the satellite systems are able to cover a specific area of interest with a fixed frequency (up to two times per day for satellites deployed in polar orbits) that can be complemented by UAVs.

6.3.2 Limits and barriers to the integration of UAVs and Satellite data

The integration of UAVs and satellite data presents difficulties which need to be addressed in order to proceed in the attempt to enhancing MSA capabilities. Among these, the following ones are particularly relevant.

One of the main limits in the aforementioned process concerns the satellites' persistency over a specific AOI of which they are supposed to acquire images in a limited, well-defined time slot. Sensors capable of acquiring high resolution images of a specific AOI are usually installed on a satellite located on a low Earth orbit (LEO). In order to register an image, LEO systems need to be directly over the AOI. However, because of the relative movement of the satellite with

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respect to the Earth, such systems are physically unable to monitor the same area at all time, and are therefore incapable of continuously obtaining pictures of it. It takes hours, or even days, for a LEO system to pass over the same AOI, and this obviously creates problems of consistency and availability. Things are different when it comes to satellites deployed in polar orbits, which are able to provide data regarding an AOI up to twice per day. Moreover, the non-persistence of satellite platforms does not allow the platform to register data of areas other than the AOI identified. Indeed, according to the mission planning activity of satellites, the on-board sensors for acquiring information are activated only during the passages on the tasked AOI. Satellite systems also have the disadvantage of presenting a high level of propagation loss. Because of environmental features such as signal absorption and dish misalignment, the level of signal attenuation might get worse and worse as the distance between the satellite and the ground receiving terminal increases. A possible way to overcome such limitation might be increasing the number of future constellation and federating all the heterogeneous space assets.

Another significant limitation is related to the age of the information derived from satellites. As a matter of fact, the distribution of ground receiving terminals is still limited and, by the time the UAV receives the satellite-derived information, the latter might already be “old”, namely referring to an area/situation which, in the meantime, might already have changed. Latency can be defined in two ways: one-way latency, or round-trip latency (RTL). One-way latency consists in the time data takes to travel from the sender to the receiver; round-trip latency is the time required for the information to get to the receiver and for a response to go back to the sender. Depending on the satellite’s orbit altitude, its latency can be more or less accentuated. Geostationary and medium Earth orbit satellites (GEO and MEO) present a delay, namely 70-200 and 0.5 milliseconds (ms) respectively. LEO satellites come with a more feasible delay, which is normally around 10-30ms. Besides the physical distance between the satellite and the ground receiving terminal, other factors more consistently affecting latency include bandwidth and the load on the network. To obviate the issue of latency, it should be considered making new investments in space economy, which will drastically reduce satellite system’s delay thus enabling NRT services on a global scale.

As far as regulations and legislations are concerned, for time being it seems like there are no significant limitations in the integrations of UAVs with satellite data.

6.3.3 Recommendations for UAV and Satellite data integration procedures

In order to reach the highest level of MSA, several measures could be implemented. Some of these address the more operational side of UAVs-satellite systems integration, and include the following:

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- *Systematic monitoring* - Extend daily maritime operations with the systematic monitoring allowed by satellites. By integrating satellite systems into such operations, it will be possible to overcome the limits imposed by traditional monitoring systems, therefore achieving a more comprehensive MSA.

- *Data fusion algorithms* - Extend the data fusion algorithms to include the multi-sensor and heterogeneous data acquired by space assets (e.g. Optical and SAR satellite, Satellite AIS, Satellites equipped for SIGINT activities). By fusing such varied combination of information, it will be possible to gather more inferences than could be collected by a single sensor, thus obtaining an effective and efficient set of data. All image-based applications would be greatly enhanced by such tool, especially given the benefits brought by some space-borne sensors' capability to integrate temporal and spatial information. Among the most popular fusion algorithms, those that present a lower level of complexity and a faster processing time also come with the issue of colour distortion. It is therefore recommended more wavelet-based algorithms are developed, as they would substantially improve performance results. In addition, the possibility of developing methods that fuse the very algorithm schemes should also be examined, as it may prove a successful strategy for the achievement of even better results. Lastly, there is the need for the creation of an automatic quality assessment scheme, which would help evaluating whether a given fusion algorithm is working.

- *UAV Automatic tasking* - Improve the procedures to speed up the automatic tasking of UAV missions starting from the information extracted from satellite images. Satellite systems are capable of detecting anomalous behaviours in the surveyed area. Once similar anomalies are identified, the satellite is able to send an alert to the UAV for its mission in-flight re-planning, but there is the need for further definition of applicable procedures.

- Federation of satellite constellations - New funds and resources should be directed towards space economy in particular towards polar stations, antenna installations, and an increased number of satellites constellations. Special attention should be given to the possibility of increasing and optimising the number of satellite constellations and creating a federation of all the heterogeneous space assets, taking into account the airspace and routes availability. Creating such a federation would obviate satellite systems' latency, propagation loss, and lack of persistency over a given AOI: by setting up a systematic monitoring of the AOI at a global level, it is possible to obtain a global awareness of the maritime domain. What is more, in case of an anomaly detection, a federation of satellite constellations would guarantee a prompt alarm generation.

Other recommendations have a more legal/regulatory nature, and include:

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Qualification - It is recommended satellite systems are qualified as full operational assets.

- *Requirements* - Define, demonstrate and validate a set of requirements for UAS-satellite cooperative missions related to:

    Communications - It is recommended further work is done for the provision of protected data connectivity for C2 communication, which need secure and reliable lines of communication between the UAV and the ground receiving terminal. The functions of C2 communications can be related to different kinds of data, such as telecommand messages, non-payload telemetry data, support for navigation aids, air traffic control, voice relay, air traffic services data relay, target track data, airborne weather radar downlink data, non-payload video downlink data, and more.

    - **Performance and capabilities** - Depending on the specific applications for which a UAV is used for in the context of a given mission, requirements on network and quality of service may vary. Satellite system's requirements for long-range communications include data rate and bandwidth. For one, experts should address the need for real time communication links between the ground receiving terminals and the UAVs. It is recommended special attention is given to multiple spot beam satellite systems which, thanks to their multiple high-powered spot beams, provide bigger and faster data pipes and guarantee a higher level of security.

    - **On-board equipment** - Depending on the application domain for which the UAV is required, different components can and should be installed on-board. Indeed, besides the possibility of carrying certain sensor equipment, a variety of other on-board navigation components can be integrated. Requirements concerning the on-board cameras, processors, position and orientation (POS) components and power supplies for the on-board sensors and the UAV itself should be delineated.

- *Operational procedures* - Establish operational procedures that may be needed, for instance, in case of emergencies, contingency plans, reacquisition strategies, or an ordinary loss of communication. In the event of lost link (LL) between the UAV and the receiving terminal, the UAV might need to land itself to an emergency landing site. If such an occurrence happens, having a contingency plan already uploaded to the UAV becomes of crucial importance.

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6.3.4 Resulting recommendations for the elaboration of procedures to integrate UAV and Satellite data

An analysis of the wide-discussed recommendations for the elaboration of procedures to integrate UAV and Satellite data are summarised in the following recommendations:

Recommendation number	Recommendation description
D662-6.3-A	It is recommended to extend daily maritime operations with the systematic monitoring allowed by satellites
D662-6.3-B	It is recommended to extend the data fusion algorithms to include the multi-sensor and heterogeneous data acquired by space assets.
D662-6.3-C	It is recommended to increase number of satellites constellations, polar stations and antenna installations.
D662-6.3-D	For safety reason, it is recommended to create a federation of all heterogeneous space assets
D662-6.3-E	It is recommended satellites systems are qualified as full operational assets.
D662-6.3-F	It is recommended further work • for the provision of protected data connectivity for C2 communication • to address the need for real time communication links between the ground receiving terminals and the UAVs. • to multiple spot beam satellite systems • define requirements concerning the on-board cameras, processors, position and orientation (POS) components and power supplies for the on-board sensors and the UAV itself
D662-6.3-G	For safety reason, it is recommended to establish operational procedures that may be needed, for instance, in case of emergencies, contingency plans, reacquisition strategies, or an ordinary loss of communication

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7 RECOMMENDATIONS FOR UNMANNED INTEROPERABILITY STANDARDIZATION

7.1 Methodology

Throughout this section, discussions will provide detail from each of the three framework tiers identified in Figure 4.

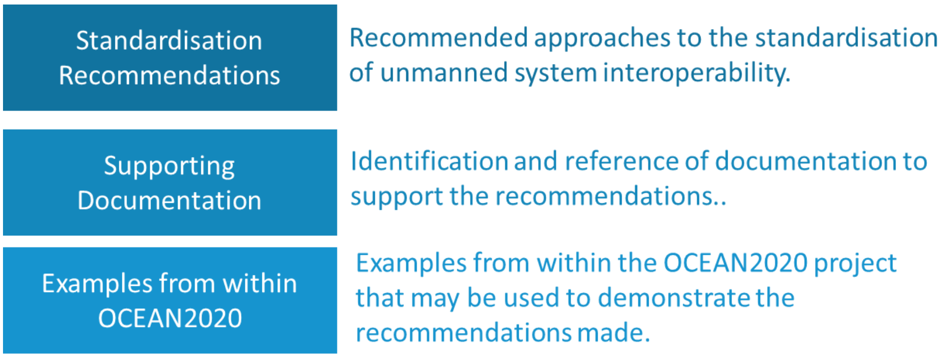

Figure 4 - Discussion Framework Suggested by CMRE

As unmanned systems increasingly become a key instrument in defence operations, the necessity for interoperability support is more pressing than ever before. Multiple aspects are to be considered, such as piloting, controlling multiple UxS by a single control station, exchange of data collected during a mission and data link interoperability.

NATO Standardization Agreements (STANAGs) are commonly used for existing systems, and are widely adopted in the defence industry. However, for the complete UxS area considering all the involved domains (ground, maritime, air and space) no STANAG has been promulgated (NATO STANAG 4817 - Multi-Domain Control Station is under development and not publicly available yet).

Within this section, recommendations for the elaboration of standards to distribute data from unmanned systems and for the elaboration of policies of cooperation between Unmanned Systems are given. However, related to the latter, only general recommendations will be provided.

7.2 Recommendations for the elaboration of standards to distribute data from Unmanned Systems

This chapter will elaborate around standards, interoperability, data distribution mechanisms and will reason about aspects to weigh together when developing architecture and solutions to achieve interoperability for unmanned systems.

The focus of this chapter is communication from unmanned systems to surrounding systems. The common pattern for an UxV system is that the system consists of the UxV(s) and related

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control station(s). This implies that communication from the control station to the UxV (s) is internal communication within the system and therefore out of scope for this chapter.

7.2.1 Data distribution characteristics for UxV-data

Data can be distributed in many ways depending on the characteristics of the distribution technologies used. In order to understand these characteristics and eventually identify which technology and standards that is best suited to distribute a certain type of data, a definition of these characteristics has been derived and provided in Table 12.

Table 12 - Data distribution characteristics

Characteristics		Description
Data type		
	Message	An individual piece of data without any dependency to any other piece of data (from a communications perspective) and is consumed when the whole message is received.
	Streaming	Data/information that has a continuous flow over a longer period of time (video/audio) and is consumed bit by bit, is produced and distributed “bit by bit” does not exist at the producer end as an object.
Data size		
	Small	A data object that is considered small in relation to transfer time (related to bandwidth as well).
	Large	A data object that is considered large in relation to transfer time (related to bandwidth as well).
Data individuality pattern		
	One to one 1-1	Each data object is for a specific consumer.
	One to many 1-m	One message or stream has multiple (unknown) receivers/consumers.
Confirmed delivery		
	Guarantee	Guaranteed delivery of data.
	No guarantee	Not any guaranties that the data is delivered.

7.2.2 Kind of data distribution

Table 13 describes the major categories of data distributions related to UxS, with different characteristics.

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Table 13 - Kind of information

Kind of information	Description and examples	Important characteristics	Distribution mechanisms
Streaming data	Streaming sensor data such as EO/IR/Radar, own position.	Stream Large 1-m No guarantee	UDP UDP multicast
Sensor data batches	Sensor data batches, such as ISR products (sonar data, still images, motion imageries) data collected recorded by UxV and later transmitted to surrounding systems at appropriate time.	Message Large 1-1 Guarantee	FTP
Control data	Control data to operate the assets for the UxV platforms and their Sensors.	Message Small 1-1 Guarantee	TCP/IP
Planning, tasking and follow up	Planning, tasking, and follow up of UxV platforms and sensors.	Message Small/Large 1-1 Guarantee	TCP/IP
Status reporting	Status reporting of UxS, before, during and after missions.	Message Small 1-1 Guarantee	TCP/IP or cyclic UDP
Notifications, Reports	Small information objects, e.g. UxS identify object and report kind of object and position.	Message Small 1-1 Guarantee	TCP/IP
Situation awareness information	Situation awareness information, e.g. providing UxS with situation awareness information enables the UxS to adapt to current situation.	Combinations of "Streaming data" and "Sensor data batches" and "Notifications, Reports"	UDP, UDP multicast FTP, TCP/IP
Target position data	Distribution of target data used for weapon systems.	Stream Small 1-1 Guarantee	TCP/IP with reserved channel or high QoS

Distribution mechanisms in table above can be replaced with different communication frameworks with similar characteristics.

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7.2.3 Standards to consider

In this analysis we take our starting point in STANAG 4586 “Standard interfaces of UAV Control System (UCS) for NATO UAV Interoperability” [R18] that define standards for UAS in 5 different interoperability levels. STANAG 4586 are then stipulating, standards that shall be used for different kinds of data transmission to and from the UAS.

The most important related STANAGS, listed in Table 14, are defined in STANAG 4586:

Table 14 - STANAGS	Name	Description
4545 [R19]	AIR - NATO SECONDARY IMAGERY FORMAT (NSIF)	Describes interoperability for the exchange of Secondary Imagery between C4I Systems.
4609 [R20]	JAIS - NATO DIGITAL MOTION IMAGERY STANDARD	Describes an exchange format for motion imagery together with metadata.
4559 [R21]	NATO STANDARD ISR LIBRARY INTERFACE (NSILI)	Describes interoperability of NATO ISR products managed by product libraries. Main ISR products as Imagery, Video, Reports, Tasks, IRM&CM (Intelligence Requirement Management and Collection Management) and other documents.
4607 [R22]	NATO GROUND MOVING TARGET INDICATOR (GMTI) FORMAT	Describes format for sending GMTI data to systems which are capable of extracting usable information from the data.

The following standards are not part of STANAG 4586, but still of importance:

For Data Synchronisation

- STANAG 5525 [R23]: Joint consultation, Command and Control and Information exchange data model (JC3IEDM).

For Interoperability Architecture

- STANREC 4777 (NIIA) [R24]: NATO Intelligence, Surveillance, and Reconnaissance Interoperability Architecture.

For Imagery:

- STANAG 7023 [R25]: NATO Primary Imagery Format (NPIF).

For Geo-spatial information:

- coreGIS: based on the standard of the OGC like the Web Map Service (WMS) [R26], Web Feature Service (WFS) [R27].

For Messaging

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- STANAG 4778 ADatP-4778 [R28]: Metadata Binding Mechanism
- STANAG 4774 ADatP-4774 [R29]: Confidentiality Metadata Label Syntax

Report Messaging

- STANAG 7149 APP-11, Ed. D [R30]: NATO Message Catalogue
- STANAG 5500 ADatP-3, Ed. A [R31]: Concept of NATO Message Text Formatting System (CONFORMETS)
- STANAG 3277 [R32]: Air Reconnaissance Request/Task Forms
- STANAG 3377 [R33]: Air Reconnaissance Intelligence Report Forms
- STANAG 3596 [R34]: Air reconnaissance Requesting and Targeting Reporting Guide

Instant Messaging

- XMPP [R35]: Extensible Messaging and Presence Protocol

For Tracks

Correlation and fusion:

- STANAG 4658 (4633 (CESMO/ELINT) [R36]: Co-Operative Electronic Support Measures Operations
- STANAG 4676 [R37]: NATO Intelligence, Surveillance, and Reconnaissance Tracking Standard
- STANAG 4162 [R38]: Identification Data Combining Process

Tactical link

- STANAG 5516 Link 16, ADatP-16 [R39]: Tactical Data Exchange
- STANAG 5522 Link 22, ADatP-22 [R40]: NATO Improved Link Eleven (NILE) – Link 22
- STANAG 7085, AEDP-7085 [R41]: NATO Interoperable Data Links for ISR Systems
- AdatP-33 [R42]: Multi Link Standard Operating Procedures for Tactical Data Systems Employing Link 16, Link 11, Link 11B, IJMS, Link 1, Link 4, and ATDL-1
- AdatP-11 [R43]: Standard Operating Procedures for NATO Link-11/11B
- STANAG 5511 [R44]: Tactical Data Exchange – Link11/Link 11B (Vol II)
- STANAG 5616 [R45]: Standard for Data Forwarding between Tactical Data Systems employing Links 11/11B and Tactical Data Systems employing Link 16
- STANAG 5518 [R46]: Interoperability Standard for the Joint Range Extension Application Protocol (JREAP)
- STANAG 4372 [R47]: (Secret) SATURN – A Fast Frequency Hopping ECCM Mode for UHF Radio

For COP/RMP/RAP

- STANAG 2019 APP 6a [R48]: NATO Joint Military Symbology
- STANAG 4420 [R49]: Display Symbology and Colors for NATO Maritime units
- STANAG 7074 [R50]: Digital Geographic Information Exchange Standard (DIGEST)

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- CFR 1910.144 [R51]: Colour Codes for Marking Physical Hazards

For Process Layer

Joint ISR

- AJP 2.1 [R52]: Allied Joint Doctrine for Intelligence Procedures
- AJP 2.7 [R53]: Allied Joint Doctrine for Joint Intelligence, Surveillance and Reconnaissance
- AIntP-14 [R54]: Joint Intelligence, Surveillance and Reconnaissance (JISR) Procedures in Support of NATO Operations
- AIntP-16 [R55]: Intelligence Requirements Management & Collection Management (IRM&CM) Procedures

Joint Communication and Information

- AJP 6 [R56]: Allied Joint Doctrine for Communication and Information Systems

Joint Maritime

- AJP 3.1 [R57]: Allied Joint Doctrine for Maritime Operations
- MTP-01 [R58]: Multinational Maritime tactical Instruction & Procedures

Data Synchronisation

- CISE [R59]: Common Information Sharing Environment for Maritime Surveillance in Europe
- MARSUR [R60]: Maritime Surveillance (MARSUR) project is a technical solution that allows dialog between European maritime information systems.

Moreover, civil sensor standard should also apply:

AIS Receiver:

- IEC60945 Edition 4 [R61]: Maritime navigation and radio communication equipment and systems – General requirements – Methods of testing and required test results
- ITU-R M 1371-4 [R62]: Technical characteristics for an automatic identification system using time-division multiple access in the VHF maritime mobile band

AIS transmitter class A:

- IEC 61993-2 [R63]: 2001-12 Clause 15, for the AIS transmitter, receiver and DSC receiver.

7.2.4 Aspects to consider

As stated in the Reference Architecture [R14] as one of the “Design Principles”, standards shall be used when available and feasible to use.

There are situations where compliance of the STANAGS are the most important concern, but still some considerations need to be done defining how to use them.

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The standards are often defined to handle many generic situations, with large flexibility when it comes to optional data fields and relation between fields, the idea is good to enable all kind of assets to be interoperable, but it comes with a price, complexity, and complexity always add costs. Often simplifications are needed to decide during the architectural work.

E.g. to be fully compliant with the STANAG 4586 when it comes to messages between the control station (UCS) and the external C4I system at integration level 5 it require about 120 different ADatP-3 messages, and for those messages there are a large amount of optional information and fields that are related to values in other fields, very complex and therefore costly to fully implement.

Some of the STANAG optimize messages sizes, by defining character oriented messages. Nowadays (last decade) the software industry utilizing tools to handle this, and let the tools check the consistence of the messages and the tools are also able to optimize the size of the messages, still in a format readable by humans. Tools exist to perform this in a large number of programming languages, enabling systems based on different languages to be interoperable, with support from the tools to ensure consistency and message size optimization.

There are different ways to limit the complexity, e.g. by deciding exactly what messages will be implemented. Another approach is to use modern kind of technique and based on information in standards that are well defined, decide relevant information that are needed to exchange in the solutions. By this you are able to use modern tools to help with the consistence control, making the risks and therefore the cost lower.

What we also need to consider are the implementation of mechanisms to use for transportation. When deciding this consider Table 13. E.g. often streaming sensor data and situation picture can be based on UDP. And other information on TCP/IP together with different application frameworks.

An example of how this can be performed are the implementation of the OCEAN2020 Baltic Sea System, se [R15] together with the defined services in [R16], in short described in Table 15.

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Table 15 - Defined Services

STANAG 4586 grouping of interfaces	Services in SID [R16]	Comment
Tasking	TaskAsset	Subset of STANAG 4586
Air Traffic Control (ATC)	None	
Collateral Data	CollateralData	Subset of STANAG 4586
Mission Plan	None	
Mission Progress	TaskProgress	Subset of STANAG 4586
Resource Availability	ResourceAvailability	Subset of STANAG 4586
Payload/Sensor Data	StreamingTrackData	Subset of STANAG 4586
	StreamingVideo	Subset of STANAG 4586
	ISRArtefact	Subset of STANAG 4586
	ReportObject	Subset of STANAG 4586
Target Data	None	
Mission Reporting	TaskReport	Subset of STANAG 4586
Services below are also provided but outside the scope of 4586		**Comment**
	GetPlatformAndEndpoint	Provides methods to ask for appropriate end points to use, and information about platform
	ObjectsOfInterest	Provide methods to publish objects of interest
	StreamingFusedTracks	Provide methods to collect system tracks, provided by data fusion engine
	EvaluationLog	Provides methods to publish log data for evaluation and analysing after preformed trial
	Alerts	Provides methods to publish operational alerts of interest
	Orbat	Provides methods to get actual Orbat
	XMPP	Standard XMPP

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7.2.5 Resulting recommendations for the elaboration of standards to distribute data from Unmanned Systems

An analysis of the wide-discussed recommendations for the elaboration of standards to distribute data from Unmanned Systems are summarised in the following recommendations:

Recommendation number	Recommendation description
D662-7.2-A	During the architectural work and design it is recommended to consider ways to limit the complexity for interoperability e.g.: • select standards to consider • limit number of messages • limit content of messages based on the standards
D662-7.2-B	During the architectural work and design it is recommended to utilize modern development tools and frameworks for e.g.: • optimize the size of the messages • check the consistence of the messages • support multiple programming languages as an alternative when e.g. complex bit-oriented standards not already are implemented
D662-7.2-C	During the architectural work and design it is recommended to consider patterns and mechanisms to use for transportation e.g.: • UDP when no guarantee needed • UDP multicast when no guarantee needed and 1-m pattern to save bandwidth

7.3 Recommendations for the elaboration of policies of cooperation between Unmanned Systems (swarming)

7.3.1 Context and scope

This section includes inputs from the execution of the Mediterranean Live Demonstrations, the First Simulated Trial, and the Second Simulated Trial. To date, swarming behaviours have not been required by, or included into, these events. Swarming behaviour will be demonstrated in the Third Simulated Trial, which is scheduled for 23 and 24 March 2021.

In the underwater domain, initial planning is already underway within the project to include autonomous squads of heterogeneous UUV's that will cooperate and collaborate to complete mission stages. The design, development and demonstration of this work is expected to be included in both the Baltic Live Demonstration and the Third Simulated trial.

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Thus, only general recommendations are provided and recommendations on the elaboration of policies for cooperation between unmanned systems taken from scientific literature.

An analysis of the general aspects of the operation of a cooperative system of unmanned vehicles is given in the section below.

7.3.2 General recommendations.

In a cooperative system of unmanned vehicles, several individuals collaborate in order to achieve a common objective. The result of this collaboration will produce a better result than the one obtained by an individual alone.

The main factors that have been identified are the following;

- The system shares a common objective for all the individual components
- The system can be composed of vehicles of different nature and capacities
- The architecture and functions need to be defined and controlled to the collaboration purpose

Hence, the system and the collaboration policies shall address the following aspects:

1. There is one common objective for the system in a dynamic environment. This will require planning and control
    a. It will be necessary to coordinate and cooperate inside the system to share a defined space/environment and also the information obtained.
    b. The cooperation of heterogeneous vehicles will involve the integration of a lot of information provided by different sensors. The information obtained about the environment or operation must be combined, analyzed and disseminated in real time in order to provide feedback to the system.
    c. Communication. Shared link between vehicle and control station that must be robust and reliable.

2. Participation of vehicles with different characteristics. The use of different platforms will allow the use of different capacities. It has to be taken into account several aspects as the following:
    a. Autonomy
    b. Flight characteristics. (multirotor, helicopters, fix wing)
    c. Sensor installed
    d. System installed as DAA systems or communication

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3. The definition and management of the collaborative system, dependent of the architecture defined, trying to optimize the use of every individual to obtain a better common objective
    a. Interoperability of the system within a defined architecture (centralized/decentralized) will be a key point
    b. The HMI infrastructure to correctly and efficiently control the system must be provided
    c. The behavior model of every individual inside the system has to be defined

So, in a cooperative system of unmanned platforms (swarms, formation or team) the same factors come into play as for a single platform (characteristics of the platform, sensors, environment, communications, information, etc.) with the added complexity of the need to cooperate with others platforms to achieve a common goal (interoperability, information processing, security in operation, detect an avoid). All these aspects must be considered when generating cooperation policies that must integrate all the existing with the new challenges that arises with this kind of operation.

The mostly used technique of cooperation between unmanned systems when acting as a swarm is the pheromone-based technique, with the Ant Colony Optimization (ACO) method [R64] as one of the most prominent methods.

Ant colony optimization (ACO) takes inspiration from the foraging behavior of some ant species. Ants are eusocial insects that prefer community survival and sustaining rather than as individual species. They communicate with each other using sound, touch and pheromone. **Pheromones** are organic chemical compounds secreted by the ants that trigger a social response in members of same species. These are chemicals capable of acting like hormones outside the body of the secreting individual, to impact the behaviour of the receiving individuals. These ants deposit pheromone on the ground in order to mark some favourable path that should be followed by other members of the colony in order to search for food. Initially, ants start to move randomly in search of food around their nests. This randomized search opens up multiple routes from the nest to the food source. Now, based on the quality and quantity of the food, ants carry a portion of the food back with necessary pheromone concentration on its return path. Depending on these pheromone trials, the probability of selection of a specific path by the following ants would be a guiding factor to the food source. Evidently, this probability is based on the concentration as well as the rate of evaporation of pheromone. It can also be observed that since the evaporation rate of pheromone is also a deciding factor, the length of each path can easily be accounted for. Ant colony optimization exploits a similar mechanism for solving optimization problems. In ACO, a number of artificial ants build solutions to an optimization problem and exchange information on their quality via a communication scheme that is reminiscent of the one adopted by real ants. [R65][R68]

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At the core of this behavior is the indirect communication between the ants with the help of chemical pheromone trails, which enables them to find short paths between their nest and food sources [R66].

ACO has a repetitive structure, which updates the pheromone trails in each iteration with regards to the direction and usage frequency of each path followed by artificial ants to move on the search graph, representing the problem to solve [R67].

An adapted ACO method, using repulsive pheromones to guide the unmanned systems may be used to guide the unmanned systems, especially UAVs, when the UxV swarm needs to cover a specific area for surveillance purposes.

If in military applications the UxVs mobility behavior must be unpredictable for an enemy, but the UxV swarm operator still needs to be able to forecast the UxVs' paths, changing the random process of the ACO method to a chaotic dynamical system might be a solution. A Chaotic Ant Colony Optimization to Coverage (CACOC) algorithm that combines an Ant Colony Optimization approach (ACO) with a chaotic dynamical system should be considered.

If the unmanned systems shall work together as a squad rather than as a swarm (i. e each UxV is performing a different task), the task allocation problem must be solved as well as the automatic re-tasking of the whole squad or group and each single unmanned asset. This leads directly to the problem of automatic reconfiguration of the squad, which must also be solved.

The most common technique used for task distribution and task allocation in a squad is that of hierarchical task networks, i. e. a systematic mapping of the difference between the initial state and the goal state of the system to tasks and sub-tasks which enable to reduce this difference.

Another technique for task distribution and task allocation in a squad is to use intelligent software agents for implementing cooperation between UxVs. Each UxV and each task will be represented by a software agent which models either its capabilities, limitations, and availability (for the UxVs), and the requirements which are linked with the tasks to be executed. The software agents will, like on a market-place, negotiate the task allocation and task execution.

7.3.3 Resulting recommendations for the elaboration of policies of cooperation between Unmanned Systems (swarming)

An analysis of the wide-discussed recommendations for the elaboration of policies of cooperation between Unmanned Systems (swarming) are summarised in the following recommendations:

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Recommendation number	Recommendation description
D662-7.3-A	If the task to be performed by a group of UxVs is surveillance of an area or another mission which requires coverage of an area, the Ant Colony Optimization (ACO) method shall be used
D662-7.3-B	If the mission or task requires that in this mission the UxVs' mobility behaviour shall not be predicted by an enemy, the adapted ACO method, which uses a random process shall be used as swarm cooperation method.
D662-7.3-C	If in addition to the requirement that the own mobility behavior shall not be predictable the operator of the UxV swarm needs to be able to forecast the UxVs' paths, a Chaotic Ant Colony Optimization to Coverage (CACOC) algorithm shall be used as swarm cooperation method.
D662-7.3-D	If the UxV group shall act in missions which require squad behavior, i. e. heterogeneous types of UxVs are deployed to the mission, intelligent software agents techniques shall be used for implementing cooperation and collaboration mechanisms.

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7.4 Recommendations for the elaboration of procedures for Control Handover of Unmanned Systems

7.4.1 Context and scope

As part of the work carried out to support the elicitation and analysis of requirements in WP1, the concept of control handover emerged as an area of great interest to both the End User and Technical communities. Several workshop discussions focussed multiple uses of handover. Hereafter, some use cases in which this functionality could be required:

- *Transit to the mission area:* this applies especially for UxS that need a dedicated infrastructure for deployment and recovery far from the mission area. This is the case for large UAVs that are deployed from a ground based control station but need to be operated from ship based control nod.

- *Extend mission area:* the range of LOS operated UxV may not cover the whole mission area. Multiple control nods can then be used to extend UxV range.

- *Perform a classified mission :* that may require a specific crew for launch and recovery and another in a different control nod to conduct the mission,

- *Control recovery in case of control node failure:* in some cases, depending on the kind of failure, the handover could permit to carry out the mission by another control nod.

Nota:

According to the use cases, it appears that handover control is less likely to be applied for UUS. Indeed, due to a combination of deployment and communication issues, along with the increased autonomy of many underwater systems, operational interest in hand-over control is strongly reduced. This is why this chapter consider the control handover only through UAS operation. For USV, even if the handover use cases are more constrained, the general recommendations drawn from the UAS study can be applied.

External facilitators in the requirement analysis workshops observed that the discussions aiming to clarify these actions were particularly complex and highlighted strongly diverging views from each of the stakeholder communities. One specific example was recorded in the generation of requirement “UAS_FUN_1060 – UAS Direct Platform Control”. During the validation workshop, this previously agreed requirement was reviewed for some time before the divergent interpretation of the requirement, summarised in Figure 5, became clear to all stakeholders.

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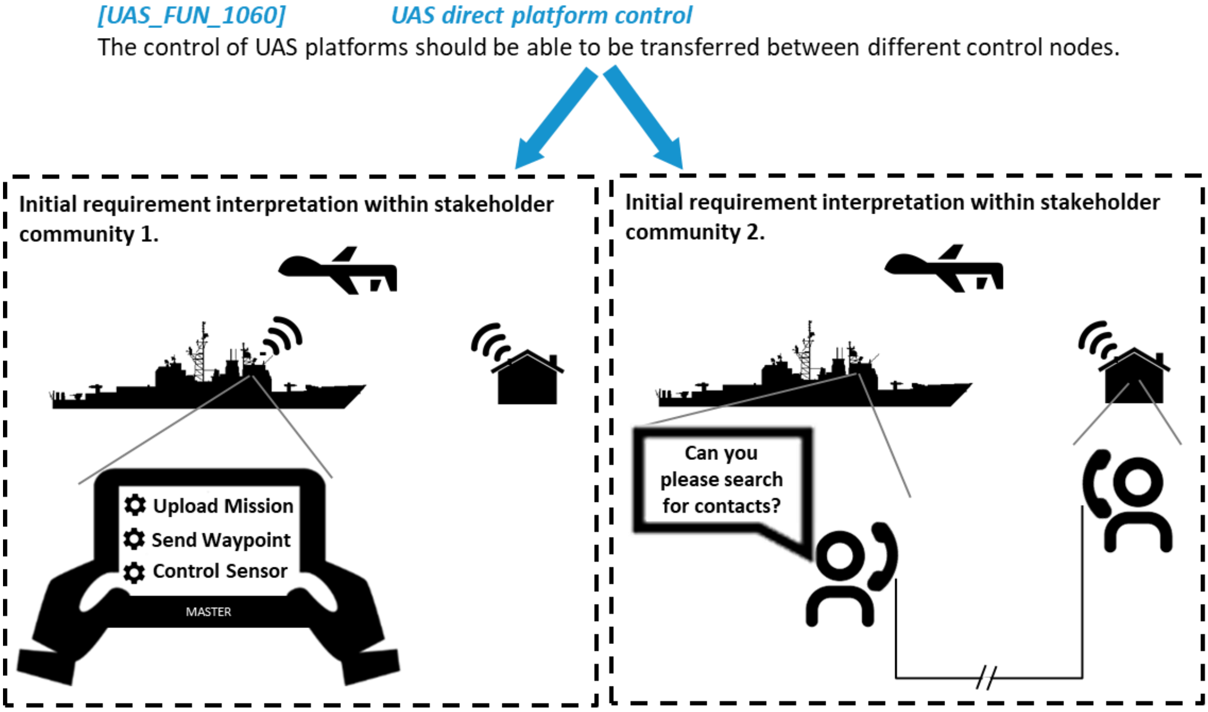

Figure 5 - Divergent Interpretations of an example handover requirement

During the requirements analysis activities of WP1, diverging interpretations around the implementation of handover procedures were further exacerbated by the complexity of the problem; requiring specialist skills in disciplines such as technology, air safety and cyber security, as well as in-depth military doctrine and tactical considerations.

One route to overcome these challenges may lie in the investigation of methodologies and approaches that support the clear and unambiguous communication among stakeholder communities. Specifically, recommendations could be made to further investigate and integrate the use of modelling and simulation (M&S) based techniques to further develop requirements and ensure that all stakeholders are cognisant of the true requirements. This approach, potentially building upon recent applications of M&S to support Concept Development and Experimentation (CD&E) activities, could provide an efficient route to identifying the true benefits and operational advantages of handover processes while supporting technical, safety and other teams to overcome the barriers to its adoption.

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7.4.2 Recommendations for the control handover between two different control nodes.

7.4.2.1 *General control handover procedure for UAS*

The general procedure described below assumes that the UAV is controlled through two different channels, which is a very common UAS architecture. Also, this procedure aims to maintain the full control of the UAV by at least one control node at any time. This procedure does not apply to “autonomous handover” that involve crossing a “blind area” with no datalink coverage between the control nodes.

Recommendation number	Recommendation description

D662-7.4-A	For safety and operational efficiency, before the handover:
	• The handing over pilot preparations:
	  ○ Perform a periodic checklist, in order to be sure that there is no malfunction in the UAV,
	  ○ Double-check the return home route. In case something goes wrong, the UAV will enter this route,
	  ○ Establish voice communication with the acquiring pilot,
	  ○ Check the UAV location in order to be sure that it is within the datalink range of the acquiring station.
	  ○ Check the UAV antennas. Depending on the system capabilities, the pilot has to pay special attention to the antenna type (directional or omnidirectional). Handing over an UAV with a directional antenna pointing to the wrong location can led to a loss link,
	  ○ During handover, the UAV shall be in an automatic flight mode,
	  ○ As a normal procedure, all control channels are to be transmitting with full power.
	• The acquiring pilot preparations:
	  ○ Establish voice communication with the handing over pilot,
	  ○ Verify that both ground transmitters are OFF,
	  ○ Verify that there is report from the UAV.

D662-7.4-B	For safety and operational efficiency, the handover shall follow the table 16 procedure

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Table 16 - Handover Procedure

Handing over station	Acquiring station
Secondary link OFF	
Check the relevant warnings	Check the relevant warnings
	Secondary link ON
Check the relevant warnings	Check the relevant warnings
Primary link OFF	
(*)	
Check the relevant warnings	Check the relevant warnings
	Primary link ON
Check the relevant warnings	Check the relevant warnings
	Check effective control of the RPA

(*)At this very moment the UAV control is under the acquiring station.

The above procedure are to be done step by step, since both pilots are linked with voice communication.

7.4.2.2 *General recommendation for control handover*

Considering control handover use cases and the described procedure for UAS, the following general recommendation for UxS can be made:

Recommendation number	Recommendation description
D662-7.4-C	For safety and operational efficiency: • The control handover shall be included in the normal procedure checklist of UxS that allow this functionality, • The handover procedure has to be arranged during the mission briefing, going through all the details, in order to avoid any misunderstanding that can lead to an UxV loss link or worse, • In most cases, the handover shall take place where both control nod datalink have good transmission margin with the UxV to cope with changing environment effect on datalink, • Handover shall be initiated by the pilot/operator in command, confirmed possible by expected new pilot/operator in command and finally granted by the pilot/operator in command,

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Recommendation number	Recommendation description
	• During all the handover phases, the UxV shall stay in the area that is covered by the datalink range of the two control nods. This often involve the activation of a full automatic mode, • If the distance between the control nodes is important, the LOS operated UxV could cross a “blind area” without any datalink coverage (autonomous handover). In this case, several aspects have to be taken into account especially safety & security considerations in addition to data management while crossing the blind area, • The UxS crew shall be regularly trained to perform a control handover in all possible contexts, • Simulators should include handover capability, since this is the easiest and least expensive method to train a crew.

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8 POLICY RECOMMENDATIONS FOR UNMANNED SYSTEM INTEGRATION

8.1 Methodology

System lifecycle guidance, such as the INCOSE Systems Engineering Handbook [R9], integration is defined as the process in which a system is realised.

A typical UxS system is describe in following Figure 6:

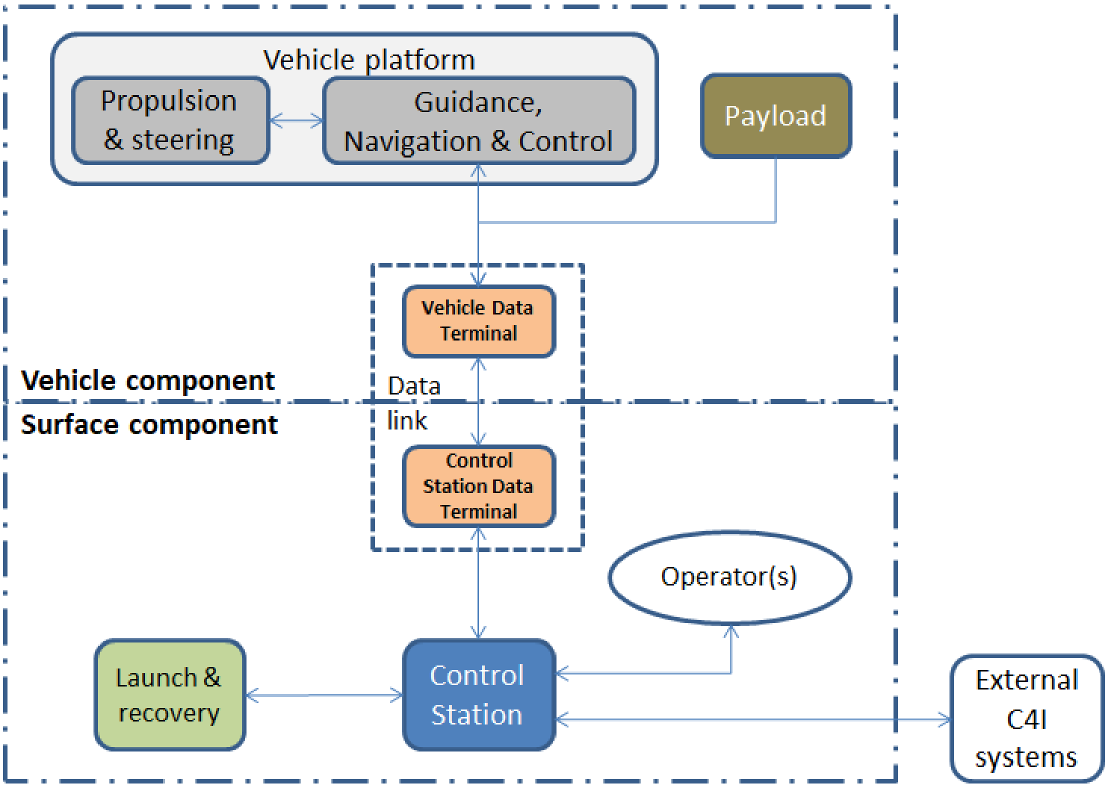

Figure 6 - Typical UxS system

By progressively combining system elements in accordance with the architectural design requirements and the integration strategy. This process, guided by the architectural design, is iteratively applied to support, and in combination with, the required Verification and Validation (V&V) Processes.

One common method to structure the integration, verification and validation stages throughout the project lifecycle is to consider the 'Vee' model of development. An example of the typical Vee model stages is provided in Figure 7.

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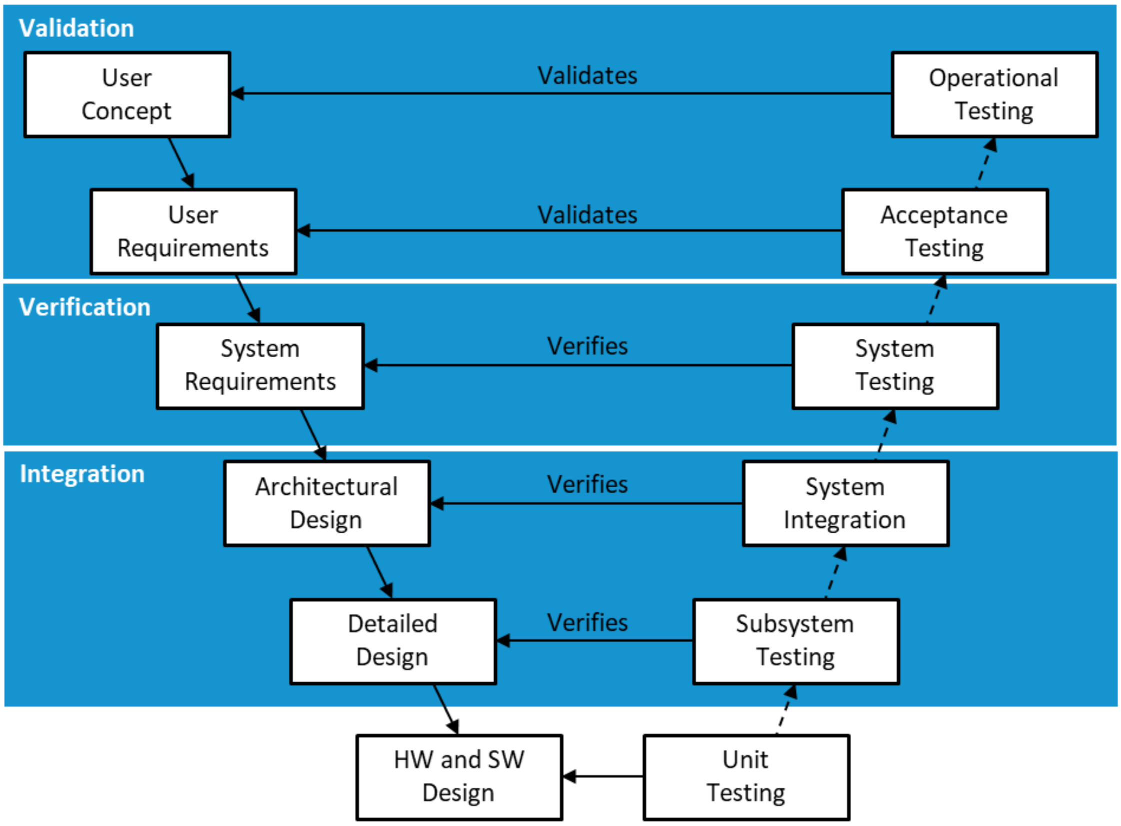

Figure 7 - Typical Vee Model Stages

This Vee model may be used throughout this section to guide as a framework and common definition of terminology on which to visualise the definition of integration, verification and validation throughout the remainder of this document.

As an example of the topics discussed at the integration level, the integration of UxVs onto Naval Units will take different approaches if the UxV is to be integrated into an existing platform or it is to be included among Combat System equipment of a new unit under construction. The main difference between the two cases is mainly focused on the physical infrastructures allocation spaces, but it can also introduce differences in effectiveness, performances, cabling, networking and software. Design, system and operational requirements of positioning, cabling, performance, coverage, human factors must be added to the design choices, when UxV has to be employed on a warship.

If the UxV integration is part of a new construction, it can be treated as one of the Combat System equipment to be taken into account while designing the whole warship configuration. Therefore all the procedures of the Requirements-Validation and Design-Verification processes are fully applicable and they can be followed as prescribed by the reference norms.

When the UxV has to be integrated on an already operative naval unit, the above mentioned processes must be adapted and downscaled as heavily as the specific integration requires.

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Moving away from the integration level, the complexity of some UxV technologies brings a range of new and potentially unsolved challenges to mature V&V approaches. One example of these challenges, that is currently an active area of research, is how to verify and validate the behaviour of autonomous systems against pre-determined concepts, user and system requirements. By considering the example of an autonomous system, challenges for existing V&V methodologies lie in providing evidence of compliance against a set of behaviours that may be continually evolving. In support of this, an approach may be taken where traditional testing approaches are complemented by modelling and simulation (M&S) based techniques by with a varying focus across the lifecycle stages. An example of this approach can be seen in Figure 8.

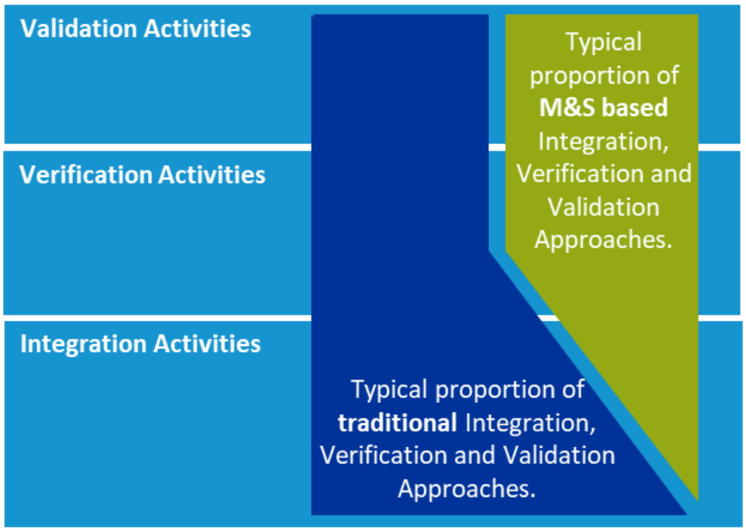

Figure 8 - A potential blend of traditional and M&S based approaches and their application to the identified test stages.

In the following paragraphs of this report, this outline approach to integration, verification and validation is commented upon further with considerations and differences among the Underwater, Surface and Air domains for both their integration with naval systems and interoperability among the scenario assets. Specifically, discussions will be structured around the conceptual framework consisting of two tiers; Policy Recommendations and Supporting Documentation. Each of these areas will be illustrated with practical examples that have been applied within the OCEAN2020 project. An overview of the description framework is summarised in Figure 9.

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Policy Recommendations	Overarching policy recommendations to guide future developments in both interoperability and integration, verification & validation activities.
Supporting Documentation	Identification and reference of documentation to support the recommendations..
Examples from within OCEAN2020	Examples from within the OCEAN2020 project that may be used to demonstrate the recommendations made.

Figure 9 - Policy Analysis Framework.

8.2 Naval Platform Integration

8.2.1 Recommendations for the verification and validation of UxV integration with naval platforms

In the next paragraphs the different testing phases are listed, with some recommendations for the specific areas and/or equipment.

As a general rule, safety has to be kept as a priority in each following integration step for people and equipment involved in UxV's operations and needs to take surrounding environments in consideration (coordination and interaction with other ships and crews).

8.2.1.1 Unit Testing

Unit testing is basically performed on land sites, even for the equipment that are on board of the ship. Technical test are normally run in laboratories and are aimed to ensure the appropriate behaviour of the unit and to verify that all the peculiarities introduced in the item by the design are working as expected. A particular attention shall be paid to build-to-specification components. Moreover the external interfaces with other units shall be formally checked in order to verify the conformity with control documents and ensure the correct interchange data formats.

Any unit has its own specificities that must be taken into account while verifying the HW and SW components. In case of new units, realized as prototypes through research and development processes, often reference norms are evolving too.

In the following list there is the set of units that are part of the UxV subsystem.

- UxV Units
  - Antennas and Datalinks
  - Engine
  - Various tools and equipment on board (depending on the platform)
  - Radar

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- FLIR System
- E/O System
- Flight / Navigation System
- Control Stations
- Inertial Platform
- Ship Cabling and Networking
- Various software (control, auto-piloting, system checks, telemetry, etc.)

- On board Combat System Units

Combat system units usually consist of commercial off-the-shelf HW components that can be considered already tested when they are purchased from qualified vendors and with conformity certificates to demonstrate the proven quality of the purchased item.

Other aspects must be tested, like cabling and integrity of the connectors that were put in place to grant power and network integrity.

Special unit test sessions are obviously reserved to software modules and to data exchange interfaces, in order to provide a continuous and correct flow of information among subsystems. Stand-alone tests for SW are carried out using simulated sources of information, trying to replicate as close as possible the final configuration of the system.

- MOC Supervision System Units

Like on board combat system units, the same approach is applied to units that are part of the land based facility at Maritime Operation Center (MOC). Off-the-shelf HW components are considered already successfully tested by the certified vendor and the focus remain on networking and data exchange among different components.

At MOC developed SW has to be tested too.

8.2.1.2 Subsystem Testing

In this phase each Subsystem must be tested in stand-alone, to demonstrate that each one is capable to accomplish its own mission and ready to be deployed in the final configuration.

In particular, the UAV must grant full operability in all the conditions foreseen by the mission scenarios, avoiding any possible interference imported by on-board surrounding subsystems (both physically and from network data).

Same approach is reserved for Combat System and MOC System. They are separately tested once the units are assembled together and configured in the target architecture. Tests for data input/output processing must be carried on in order to confirm that the designed subsystem is responding to its specific requirements.

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8.2.1.3 *System Integration*

- UxV with Combat System
- Combat System with MOC Supervision System

To test data exchanges and verify the nominal and non-nominal behaviours of the components foreseen in the Architectural Design Phase

Naval platform networking infrastructure:

The integration of UxSs into naval platforms introduces significant challenges related to the internal IP network of the naval platform and the link backhauling data from the naval platform to higher layer, offboard C4I systems in terms of available bandwidth and QoS support, since networking aspects in the design phase are often considered as a minor issue to be postponed to integration phase. The experience tells another reality, which requests to carefully design any new addition to a complex, multi-security layers network like the one on board of an operating warship.

V&V processes should focus on:

- Security, including penetration testing
- Bandwidth & QoS in an end-to-end fashion

8.2.1.4 *Validation System Operational testing (dry run and demonstration)*

The final goal is to prove that the Full System (with all the components active and running) is ready to be put into action in a safely and effective scenario execution.

Before doing so, full capabilities tests (preferably in quasi-real conditions at sea) are requested to validate all the functional chains involving the UxV, the mother ship and the land facilities in order to verify all the technical, performance and operational requirements.

When coalition and fleet exercise is foreseen, it is mandatory to execute the full mission scenario together with other warships and assets in order to demonstrate capabilities and performances in the operational environment.

8.2.2 Recommendations for the verification and validation of UAV integration with naval platforms

When an UAV has to be integrated on a Naval Platform, operational requirements mostly deal with safety of the flight operations in terms of equipment, ship staff and civilian in the area of operations.

On the other hand the system requirements define the performances and capabilities to be expressed by the UAV.

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Integration must assure command and control efficiency and safety on 360° up to the operational limit of the flying unmanned asset.

The general requirement above implies the need to:

1. Respect of flight restrictions, norms and standards issued by relevant authorities
2. Provide effective operational setup of the equipment on board
3. Ensure full-operational control during any movement of the UAV within the technical boundaries
4. Apply redundancy measures to ensure fail-safe behaviours of the system
5. Minimize interferences (physical, mechanical, electro-magnetic, thermal etc.) with other ship equipment to avoid performance degradation of Platform Systems
6. Monitor air traffic around the unit and prevent any possible risk for the civil and military flight operations

Just to provide an example of the above mentioned adaptations, in the Italian Ships integration solution for Ocean2020, ship navigation and attitude data couldn't be received by the ship's Navigation System. Therefore the design required to add an extra differential GPS to be installed on the top side in order to provide ship kinematic data and assets to the control system of the AWHERO UAV.

Following the same example, another design decision forced by the integration on an operational warship was the positioning of the AWHERO UAV UHF control antenna. When the UAV is operated on the ground, there is a single HW equipment to grant 360° azimuth control of the flying object was.

During the Electro-Magnetic Compatibility studies and the survey on board there was no safe position for a single antenna, therefore a solution with 4 antennas (two on the fore section and two in the aft section) was realized.

In the Verification and Validation phases, extra tests, with respect to the on-ground system configuration, were added for the additional Units and for the UAV Subsystem in order to verify the architectural design.

Following the diagram in Figure 7 (in the methodology section), Verification test activities have to be executed at three levels of the design: Unit, Subsystem and System with the objective to confirm the design choices (HW & SW, Detailed and Architectural).

In an industrial product development context, the validation is performed through controlled scenarios and a formal acceptance test shall be passed. For demonstrators, the validation is limited to the operational results achieved during the demonstration ensuring the feasibility of the solution.

In the next paragraphs the different testing phases are listed, with some recommendations for the specific areas and/or equipment

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8.2.2.1 *UAV integration Units Testing*

UAV's components are derived from aeronautic solutions and cannot be fully validated through existing standards.

Just to have a peculiar example, avionics of an Unmanned Rotary Wing Aircraft are significantly different from the standard aeronautic systems and therefore many of the existing, well-established control check lists are only partially applicable. Whenever it happens, specific test plans and test procedures must be adopted.

In the following list there is a possible set of units that are normally components of a generic UAV subsystem.

- UAV Units
    - Antennas (on board of the UAV and their terminals on the mothership or base station)
    - Engine (with its moving components like rotors in case of helicopters)
    - Flight System
    - Avionics
    - Payload
        - AIS receiver
        - Radar
        - Flight IR Camera
        - E/O System
    - Asset Control and Inertial Platform System
    - Remote Piloting Control Station
    - Mission Control Station (Payloads, backup pilotage, technical panels, etc.)
    - Secondary Control Systems (Emergency Base Console, On-deck Operator, etc.)

Just like the UAV the Units of Combat System C2 include:

- Cabling and Networking, which are required to extend the perimeter of Combat System when including an UAV as additional subsystem
- Electronic Network Units (Rack, Routers, Switch, Firewall, Server, Monitor)
- C2 Consoles
- Communication System (radio and satellite)with UAV and MOC
- Interconnection with other on-board systems
- Software suite to add/integrate UAV and MOC information in the combat system

MOC Units include:

- Cabling and Networking which are less complex than Naval Units one, because of the spaces, supports and infrastructures available on land.
- Electronic Unit (Router, Switch, Server, Monitor)
- Consoles and Large Screen Displays for the Operations Room
- Communication System (with Naval Unit)

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- MOC Software for the Operations Room
- Interoperability tools and interfaces with other MOC legacy systems

Each Unit must follow its own Test Plan and Test Descriptions to grant full compliancy with the specific HW and SW design of the unit itself, with the objective to qualify each component before assembling the main unit for the full system test campaign.

8.2.2.2 UAV integration Subsystems Testing

After assembling all tested units into each component subsystem, it is required to verify that the requirements and expected performances are fulfilled by each macro-item that us part of the system.
UAV integration in a maritime surveillance system can be divided, following the scheme described in the previous paragraphs, into three main subsystems:

- Aerial Vehicle - UAV
- Combat System add-on for UAV integration
- Module for UAV Supervision System at MOC

This phase requires that each subsystem is tested in stand-alone mode in laboratory, in test facilities and in the scenario environment.

The three test facilities are executed in an escalating complexity of activities, starting from technical checks of functional chains of each flight phase, moving to brief vertical flights for trials of take-off and landing up to fly complete missions to test endurance and distance of control systems.

Following the above tests plan, tests must be carried out to verify the different functional chains for:

- Data exchange with base stations and consoles:
  - Antennas and Datalinks Electrical Checks
  - Exchange SW Configuration settings
- Piloting Control Station effectiveness
  - Software configuration settings
  - Network interfaces settings
- Mission Control Station effectiveness
  - Software configuration settings
  - Network interfaces settings
- On board networking
  - Data exchange among UAV units
  - Network tools (switch, routers, etc.) configuration settings
- Testing the UAV payload datastream to the Control Station
  - Assess datalink bandwidth

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- Assess correct network configuration
- Assess Control Stations communication

- UAV development flights
  - Datalink coverage (azimuth and range) assessment
  - Antenna coverage (azimuth and range) assessment
  - Command and Control execution of Piloting Control Station orders
  - All Payloads orders execution from Mission Control Station
  - UAV piloting handover between different Piloting Control Station (e.g. Land-based Air Facility and on-board station at sea)
  - UAV Payloads command and control handover between different Mission Control Station
  - Obtaining clearance for flights from relevant entities
  - Testing the safety procedures
  - Checking possible alternative landing spots for emergency procedures

Adversarial Tests simulating most common failures to check UAV behaviours.

8.2.2.3 *Full System Integration*

With the subsystems positively tested, the final integration phase can be activated.

The Integration test phase can still be designed as an incremental process, in order to proceed with parallel tests in different conditions and in different test facilities.

- UAV testing on board with naval unit Combat System
- Warship Combat System with UAV Supervision System at MOC

Both activities require the availability of the warship that becomes the main actor for the test campaign.

The UAV integration must be performed directly on board with all the staff embarked and operative on the deck and into technical areas of the ship. It requires a serious involvement of the ship crew and the availability of going at sea for specific flight routes and into specifically reserved area for unmanned flights in safe conditions.

Flight operation with UAV is as impacting as normal helicopter management operations when assessing the interference with on-board systems and duties. Therefore it requires a high level of cooperation between operational crew of the ship and system technical and managerial staff.

The Ocean2020 experience on board of Italian FREMM Frigates has highlighted that a safe amount of ship's availability time for this kind of demonstrations is 6-7 months from the start of the ship physical upgrading until the demonstration.

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The second activity relies on satellite link connection and can be performed while the warship is on duty, providing that it is operating in area covered by the selected satellite constellation.

Tests are more probative the more complete is the technical chain under test. It means that any simulated, emulated or missing component can provide false positive or false negative feedbacks, which can slow down the process.

Most of the issues emerging from the integration campaign tests are usually networking and software problems that must be quickly tackled with a systematic approach of Software problem Reports management.

Costs for repeating UAV flights at sea, with full technical and operational crew embarked, and the short times reserved to the final integration trials can heavily impact the timeline and the budget of the campaign.

8.2.2.4 *UAV integration Validation through Operational testing (dry run and demonstration)*

In an industrial process, a formal acceptance test plan shall be passed to ensure that the full system meets user requirements in terms of available functions and associated performances. For a demonstration, the achieved results will be considered as the demonstration that validates the designed solution. However, before the main event of the demonstration, dry run exercise which usually consists of an unofficial trial is performed. It gives the final feedback on the validity of the implementation and allows testing the last modifications inserted after problem corrections.

Boundary conditions on dry run must be as close as possible to the operational context of the exercise. Of course many variables cannot be fully controlled (e.g. weather, wind, sea state, etc.) and it is very probable that in dry run the scenario can be completely different from the demonstration days.

Technical tests are now fully executed with the complete check of every single functionality and functional chain, ranging from the UAV data transmission toward the main MOC supervision room up to the transmission of data stream among ships of the fleet or to remote entities.

8.2.3 Recommendations for the verification and validation of USV integration with naval platforms

Surface domain is for some aspects similar to air domain (communication in the air, movement regulated by rules,…) and for others similar to underwater domain (propulsion through water,..). As a result, most of recommendations of these domains also apply to USV integration with naval platform.

In this part, specific integration issues related to the USV are emphasis especially for subsystem testing.

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8.2.3.1 Unit testing for USV integration

General recommendations developed in section 8.2.1.1 apply to USV.

Additionally, it can be added following information that are applicable to all UxV:

- Vehicle logs are an essential source of information for verification testing but also for further development and eventual training of operators. It is important to revise vehicle logs and the associated meta-data for continual improvement as the sensors, processing and vehicles may evolve over time.

- Sensor element level data, range, signal to noise ratio, data logging: all sensors require testing in air or in water before long operations to ensure that vehicles are not dispatched when not ready.

- On board processing capability, GPU V&V, storage, input data, output data: In general, on board processing is developed in the first instance on historical data and is tested systematically over a large set of testing data offline. Metrics of performance of algorithms are designed carefully to ensure that all scenarios have been captured as much as possible. Once algorithms have passed an acceptance test offline, these are ported on board a vehicle and tested again. It is important to test these in conjunction with sensors and computing capability as memory leakage can occur over time, latency can impact results and processing failures can follow as a result.

8.2.3.2 Subsystem testing for USV integration

Deployment/recovery : Methods for USV deployment/recovery from a naval platform are unique to each USV type/ship type pair. As such, their design, integration and subsequent verification/validation can be very challenging, especially when the USV is integrated onto existing naval platforms. Special care has to be taken with regards to:

- How the USV will approach the naval platform to be recovered and how it will separate from the naval platform after deployment
- The maximum USV weight which can be accommodated by the deployment/recovery mechanism
- The dimensions and anchoring points of the deployment/recovery mechanism
- The processes and roles involved in deployment/recovery operations, including the time necessary to perform deployment and recovery

A V&V test plan should include all necessary test cases and acceptance criteria to sufficiently cover all abovementioned aspects throughout the entire range of operational conditions (sea state, wind speed & day/night).

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Surface-to-surface communications : The need for increased data rates normally mandates that the USV communicates with the host naval platform over a wireless data link. Surface-to-surface RF communication is especially challenging due to:

- Increased multipath effects, specifically when approaching large metallic objects such as ships and port equipment
- Reduced LOS range due to the fact that antennas cannot be placed sufficiently high above the water surface
- Electromagnetic compatibility, since a naval platform hosts numerous emission sources at various frequencies
- Space restrictions with regards to antenna placement in conjunction with communication range requirements which mandate installation as high above the water surface as possible

Processes related to V&V of the surface-to-surface communications should aim at:

- Quantification of the actual achievable range for a set of rates and possible antenna placements, including both coverage studies and field tests
- Verification of a suitable level of electromagnetic compatibility using simulations during the design phase (always depending on the placement of the antennas) and measurements prior to and after the installation of the communication systems

8.2.3.3 Full System integration

Considerations developed in section 8.2.2.3 apply also to USV.

8.2.3.4 USV integration Validation through Operational testing

Considerations developed in section 8.2.2.4 apply also to USV.

8.2.4 Recommendations for the verification and validation of UUV integration with naval platforms

The underwater domain presents a range of specific challenges across each of the integration, verification and validation activities identified in Figure 7 of the methodology. These challenges range from additional rigour required in the integration test of vehicle components that are used in hostile saline and high pressure environments in which human interaction in the case of a failure is often not possible, to the complication of describing, specifying and testing advanced levels of artificial intelligence and autonomy. To articulate these underwater domain specific challenges, this report will consider actions that cover each of the 'traditional' and 'modelling and simulation' methodologies that, distributed as indicated in Figure 8, have been used on the OCEAN2020 project to advance the maturity and capability of a range of methodologies.

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8.2.4.1 Unit, subsystem and system testing for UUVs integration

When considering unmanned underwater vehicle (UUVs), the system integration test activities highlighted in Figure 10 can be viewed as a composition of three main subsystems:

- The platform
- The sensing capability (payloads)
- On board vehicle intelligence and processing capabilities

Traditionally, these three components are fully tested and verified separately as much as possible and then tested together to ensure that the combination the subsystems do not interact negatively together. As such, the recommendations to the integration, verification and validation of UUVs with a naval platform follow the conventional stage approach of sub-unit testing and combination thereof.

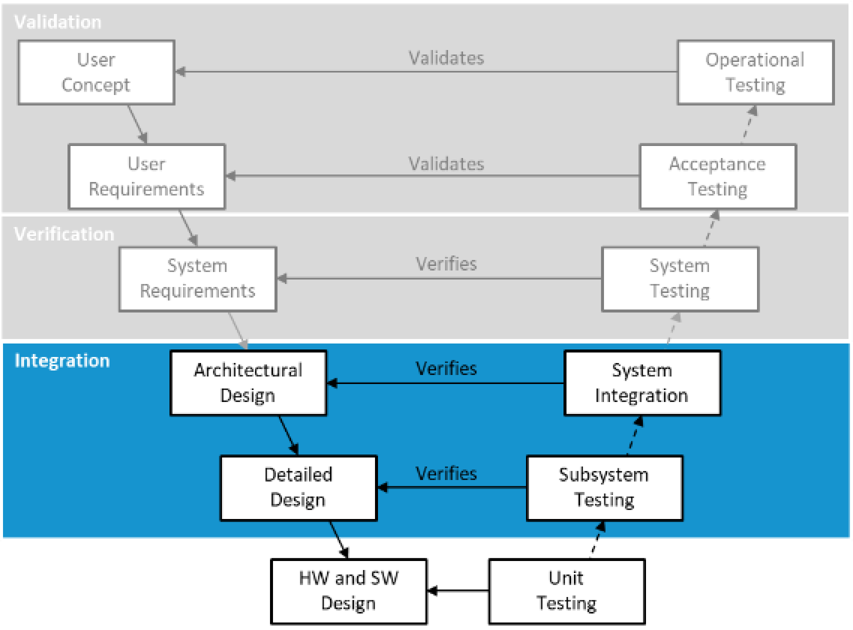

Figure 10 - Integration Test Elements

Integration UUV system itself is a crucial first stage and each individual element is tested against low-level requirements, using data sources obtained from both historical data and scenarios and further live in operation without a naval platform.

In the first instance, OCEAN2020 consortium recommends tests of vehicles through a set of gradual tests in very controlled conditions from shore.

Engineering trials are staged in three phases: a pure vehicle phase, sensors tests and on-board processing. After each component has been tested, dedicated experiments with clearly defined goals and metrics are performed to test the various combinations:

- Vehicle + sensor
- Sensor + off-board processing

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- Vehicle + on-board processing (that does not require sensor, autonomy for example)
- Vehicle + sensor + on-board processing

The main observations from the preparation of OCEAN2020's Mediterranean Demonstrations and previous experiences can be summarised in the following points:

- *Vehicle deployment and start of mission:* Without any platform interference, the vehicle deployment process can be refined by developing mechanical and electronic launch and recovery systems. The process to launch missions also needs careful planning and validating from a standard operating perspective, for example, a remote controlled start of the vehicle propulsion may lead to a hand-over to the vehicle's internal control system at a certain distance from shore (or platform).

- *Vehicle stability, navigation, buoyancy, propulsion and communication:* underwater vehicle navigation is of a concern for multiple reasons. The vehicle cannot track its own position with the same accuracy as terrestrial or airborne systems. Inertial navigation systems offer good performance but drift over distance travelled and any objects or threats detected lose positional accuracy as a consequence. Naval platforms may track underwater vehicles with underwater positioning systems via acoustic communication means and can aide in navigational uncertainty, but the performance of such systems is environment dependent and may impact the manoeuvring of both the vehicle and platforms. Concepts of operations and concepts of use need to be clearly defined to enable the safe and optimal use of underwater vehicles when sharing space with surface platforms. Propulsion uses power and may take away vital energy from the sensing payloads and smart processing; this may require a surface asset to bring the UUV closer to the mission area for example. Finally, acoustic communication underwater is limited, intermittent and suffers from latency. Wired communication will face water column dragging strength and underwater connections challenges. Testing of the communication is crucial to understand the limitations of operations and assess the appetite for risk. A concept of use of UUVs needs to clearly define the communications strategy (type of umbilical, characteristics of acoustic link), the eventual surfacing at regular intervals for example to check in and transmit surface messages at long distances and in the worst case scenario, distress signals in case of failure must be automatically sent and received.

- *Vehicle autonomy is largely dependent on a national appetite of ambition*; the vehicle autonomy can range from missions that do not deviate from pre-mission operator inputs to fully intelligent systems that are difficult to predict in variable environments. The level of autonomy largely drives the verification tests that can be implemented, but standardised metrics given a mission objective should be defined. For example, in the case of mine-hunting a percentage clearance is an accepted measure of conventional Mine Counter-Measure (MCM) missions. However, given the advance in

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technology and processing, it may be useful to define higher resolution concepts and maps to enable a better integration with platform situational awareness.

- Vehicle end of mission: it is important to define the criteria of mission completion and the appropriate behaviour of the vehicle. Communication with the vehicle becomes of utmost importance either to ensure download of critical information from the vehicle but also to ensure a follow on mission or recovery.

- Additionally, vehicle logs, sensors logs and on board processing test developed in section USVs also apply to UUVs.

Conceptual modelling activities, such as those described in the NATO Architectural Framework (NAF) [R10] may be used to support the definition, specification and testing of sub-system and unit elements through approaches aligned to the Model-Based Systems Engineering (MBSE) philosophy.

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8.2.4.2 System testing to verify system requirements

Following the completion of integration testing of the UUV system, the integration with a naval platform enables system testing and verification activities, as indicated in Figure 11.

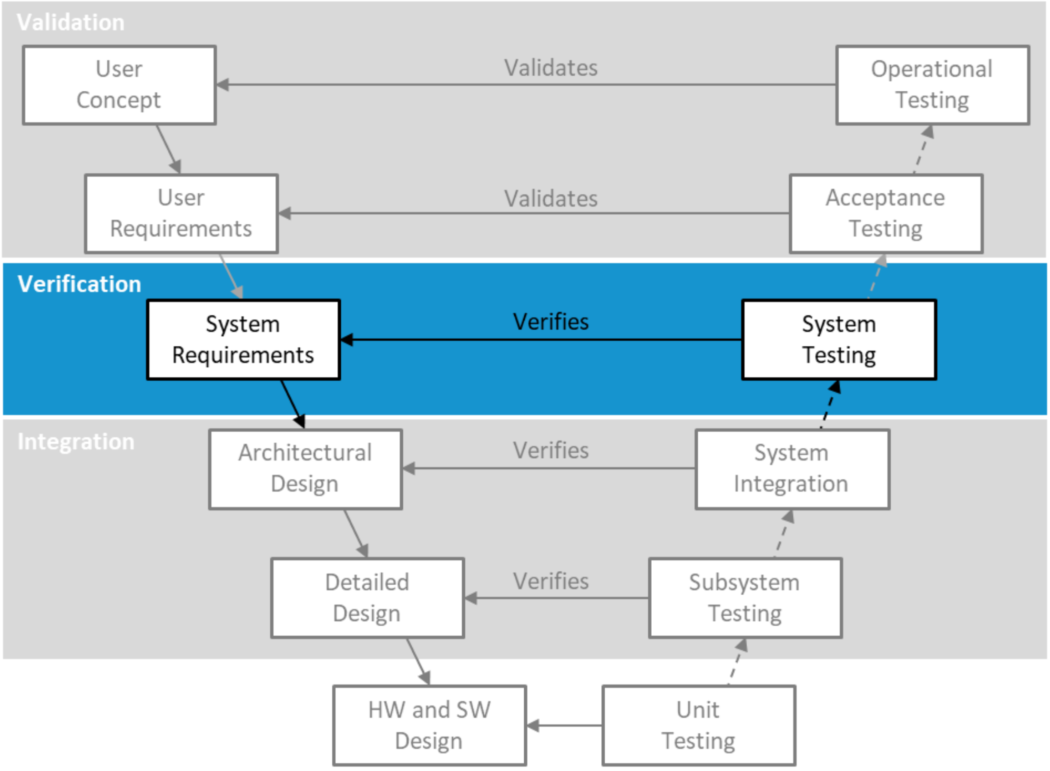

Figure 11 - Verification Test Elements

If the modular and containerised approach to integration testing has been applied as described in section 8.2.4.1, then it is anticipated that the integration onto a naval platform is made easier.

An initial stage of testing may be conducted through a controlled exercise of well-known and characterised environmental conditions, known target positions and a gradual verification of the different functionalities of a UUV deployed from a naval platform:

- *Deployment from a platform*: The integration with the platform should verify that deployment and recovery is safe and efficient and under which conditions. This should form the basis of a standard operating procedure for each system and for each platform.

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- *Communication links between the UUV and Naval Platform*: Control of a vehicle at the start, during and end of a mission should not be hampered or interfere with platform communication systems. Additionally, communications during the mission are crucial to enhance operator situational awareness, enable a possible operator take over and address eventual navigation errors. These links need to be tested in multiple environments; acoustic communication suffer greatly from limited bandwidth and so a performance estimation of range and bitrate is essential during the integration of a vehicle onto a platform. Fibre optics or other type of umbilical or tethers need to be carefully integrated to avoid too many limitations on mothership manoeuvrability.

- Information between UUV and the naval platform (for example, correct upload of mission information from Platform to UUV, correct information received at the platform from UUV on status, position, processing outputs) is dependent on the communication means; this connection should also be tested in different conditions and missions to ensure that the information itself is comprehensible and can then be viewed by the command and control stations of the operators and commanders.

- Navigation tracking from platform: it is advantageous to design the vehicle system such that it can take advantage of any platform tracking systems in order to correct for navigational errors environment permitting.

- *Vehicle autonomy:* the interaction of a vehicle with the ship should come under a standardised water-space management plan and should include systems to ensure that the vehicle is aware of the platform and vice versa.

- *Vehicle logs:* it is key to perform lessons learnt from the logs and deployments for improvement of integration with a naval platform, i.e. logistical, mechanical and personnel.

- *Sensor element level data, range, signal to noise ratio, data logging*: At shore, this is trivial to implement, however, sensor fail-safe checklists need to be designed for operator use when integrating into a platform. Additionally, interferences may occur with multiple systems in the water and a water-space management plan (in terms of frequency use) is also recommended when integrating with naval platforms.

- *Vehicle end of mission:* The integration of the recovery phase with a naval platform should also be derived into a standard operating procedure with the scrambling of a dedicated team to ensure safe and efficient recovery of the vehicle but also secure download of collected data and information.

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Controlled exercises should commence in benign conditions and be repeated increasing the complexity of conditions and mission objectives.

Further, at this stage of testing, modelling and simulation (M&S) methodologies can be used to support the system's development and integration onto naval platforms by following two conceptual approaches: 'M&S as an input to the system under test' and the system under test as an input to M&S'.

In the first of these cases, M&S can use used to generate a virtual environment that feeds environmental inputs, such as those received from the systems sensors, in real hardware or software in the loop. The benefit of this approach is that complete systems can be tested in a variety of complex environments the cost, time or risk associated with testing systems at sea. As a specific example, Figure 12 provides an example from the OCEAN2020 program where the M&S capability developed as part of the project was used to test software that ran in the project's UUVs.

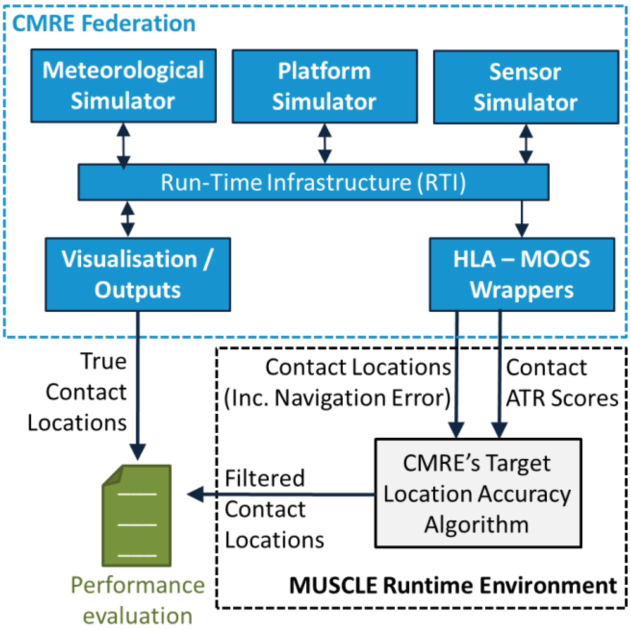

Figure 12 - The architecture used to enable M&S to test operational software algorithms as part of the OCEAN2020 Program

This test, where the actual software module was run in its operational runtime environment, allowed an understanding of the software's operation and robustness to be understood prior to commencing in-water tests.
In addition, M&S can be used as an output to collect data and visualise the performance of the system in a range of environments. These outputs may be in the form of either intuitive three-dimensional visualisations or via an interactive analysis of datasets produced by the results. An example of each of these outputs a provided in Figure 13 and Figure 14. It should be noted

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that these outputs are of particular relevance in the underwater domain where UUV operations cannot be monitored in real time during their operation at sea.

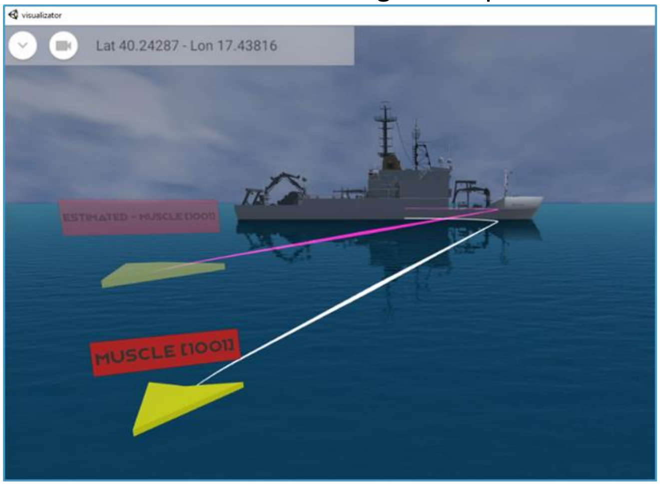

Figure 13 - M&S as an output: Intuitive 3D visualisation.

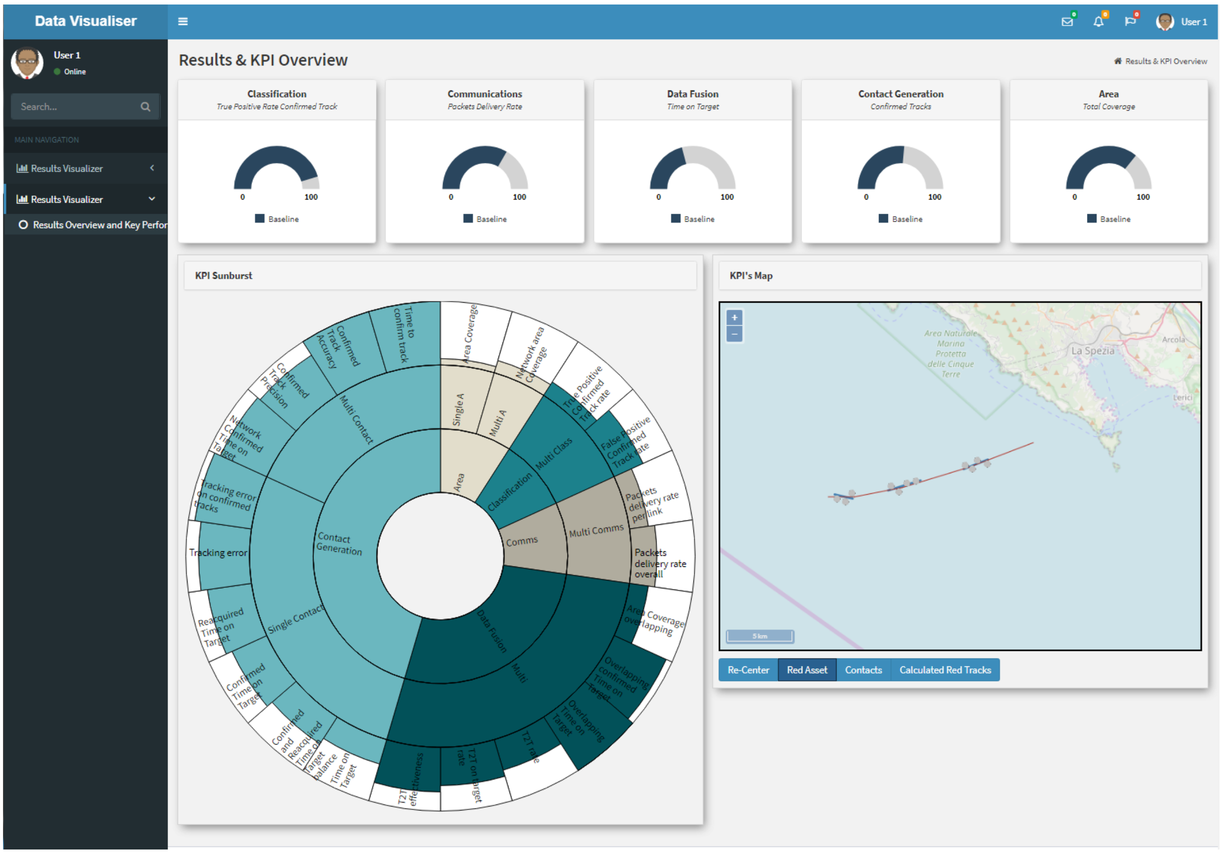

Figure 14 - M&S as an output: Data Analysis.

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The benefits of using M&S as an output focus on the ability to understand complex system level behaviors and their impact on the higher level functions.

8.2.4.3 Operational and acceptance testing to validate user concepts and requirements

Finally, the validation consists in comparing the overall performance of unmanned systems in two cases:

- In the first case, when UUVs are envisioned to replace conventional platforms, it is important to run comparative exercises in identical conditions between legacy and new capabilities. This is to ensure that future solutions offer the same capabilities if not better.
- In the second case, the performance of an unmanned system must be validated against concepts of use and operations. Experimental tactics need to be developed to define the scenarios, deployment and planning strategies and metrics of performance.

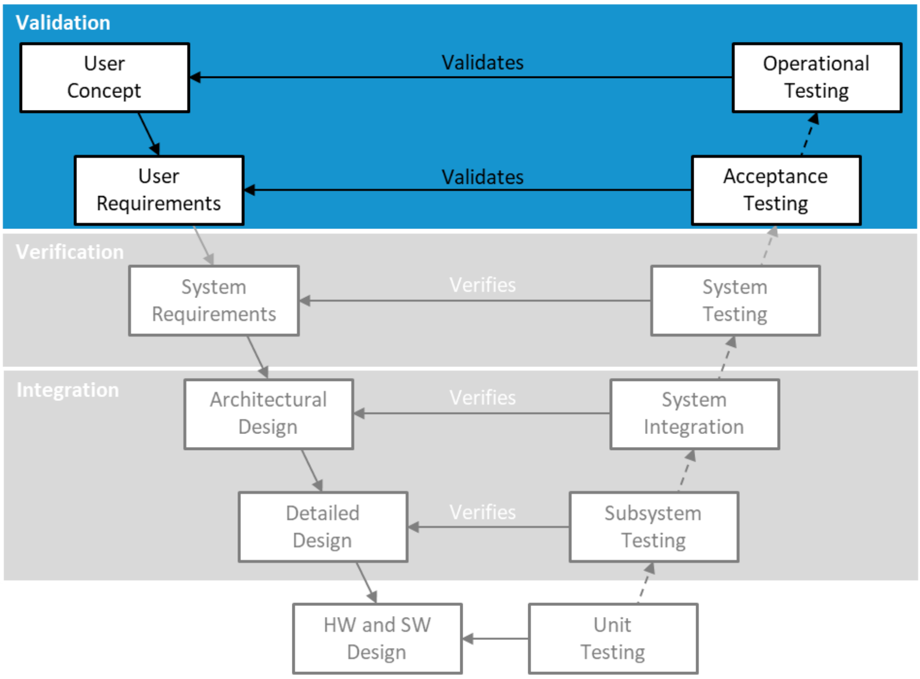

Figure 15 - Validation Test Elements

This traditional approach faces two key challenges when applied to the validation of technologies and systems enabling the development of autonomous and unmanned UUVs; The first challenge relates to the step-change in performance and complexity required to define and test evolving system elements, such as behaviour. The second challenge is in the area of maximising the impact of UUVs in operations, where simply adapting approaches based on manned platforms may be less effective than considering completely new ways of working.

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In the air and surface domains this challenge can be partially addressed by demonstrating the systems during a controlled scenario. In these scenarios, near real time updates of both telemetry and sensor data are available to the operators throughout the mission via a selection of radio networking options. Further, the use of autonomy in UAV and USV platforms is typically limited to rules that are followed during specific events such as a loss of radio link or component failures within the system. Conversely, underwater domain does not permit the in-mission control of the platform or monitoring of sensor outputs due to the absence of high bandwidth datalinks[2]. To mitigate the inability for systems to be guided by human interaction, high levels of autonomy are required to guide the system, not only in emergency situations, but through entire missions. One route to address these issues is with the use of M&S approaches in both the development of novel concepts of operation as well as the testing of solutions to enable these concepts to be realised.

To develop new operational capabilities, NATO typically uses its Concept Development and Experimentation (CD&E) process [R11], defined as a technology agnostic approach that supports the proposal and test of a range of potential future concepts of operation in all military fields. Key to the concept of CD&E is the use of a spiralling approach, with iterating and separate concept development and experimentation stages. The iterative, spiralling approach is managed in a series of increasing Capability Maturity Levels (CMLs), an overview of which is provided in Figure 16.

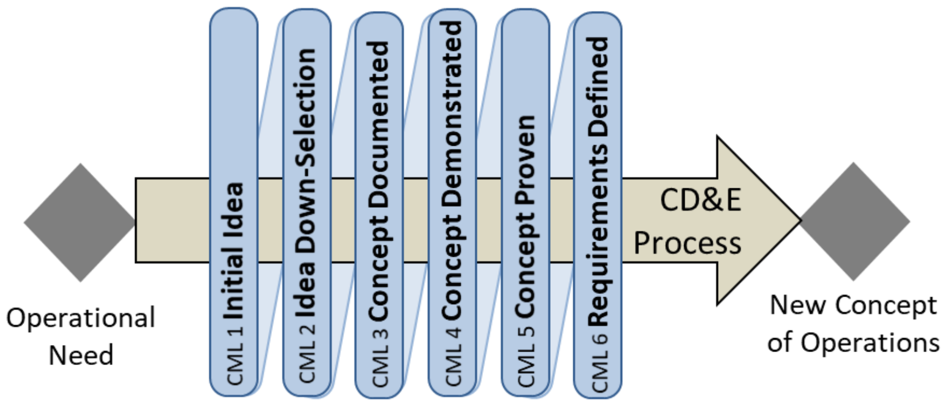

Figure 16 - Overview of the NATO CD&E Process

Throughout the complete CD&E process, the broad concept of 'modelling' should be considered. While computer based modelling and simulation is a valuable tool throughout the process, conceptual modelling activities supported by NAF guidelines can achieve significant benefits in the early stages of the process with particular benefits its ability to encourage and support the continued communication between technical, operational and other specialised

[2] Here we willingly put ROVs to the side as they have no self-decision autonomy and their operating feedback is immediate (video cameras are available) and integration and validation tests are much easier to assess.

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communities. As the maturity and complexity of the concepts under development grows, computer based M&S may play an increasingly large role, resulting the ability to execute complete missions and articulate the impact of complex and coupled behaviours on mission performance. This was demonstrated in the 1st OCEAN2020 simulated trial, where the industry standard recommended practice for Distributed Simulation Engineering and Execution Process (DSEEP) [R12] was successfully applied to connect a wide range of geographically distributed domain and technology specific models to provide a scenario-wide simulation capability to foster greater understanding of each of the project's technical and operational capabilities.

The output of this process is typically a commonly understood set of novel conceptual requirements and concepts of operation that can be used to structure the final validation testing of the complete system. As the sophistication of autonomous system behaviours grows and the potential number of use cases increase, a barrier is presented in the ability to robustly test all use cases. Again, emerging M&S based approaches may support the completion of this testing in a timely and efficient manner. Specifically, further investigation made be made into the design of experiment approaches to system-wide testing, along with an evaluation of the potential benefits of parameter effect propagation analysis to control the number of required test cases while maintaining robustness of the test coverage.

8.2.5 Resulting Recommendations for VV&A of UxVs integration with naval platforms

An analysis of the wide-ranging and detailed recommendations for VV&A activities related to UxVs integration with naval platforms has produced the following summarised recommendations:

Recommendation number	Recommendation description
D662-8.2-A	• **Integration** ○ Integration activities should focus on subsystem testing and system integration. ○ Integration testing activities should consider the separate testing of UxV platforms, payloads and intelligence capabilities. ○ Test stages should iteratively build in complexity. The observations made in OCEAN2020's Mediterranean Demonstrations may be used as a baseline example. ○ Integration testing may benefit from the use of conceptual modelling principles to clearly define the required system component and the interfaces between them.
D662-8.2-B	• **Verification**

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Recommendation number	Recommendation description
	○ Verification activities should focus on system testing. ○ Initial test stages should be based upon well-known and characterised environmental, geographic and functional inputs. ○ Controlled tests should be repeated, increasing the complexity of conditions and mission objectives. ○ M&S may be utilised to provide inputs to the system under test, allowing inputs to be provided that are not possible in traditional testing, especially for UUS. ○ M&S may be utilised to capture outputs from the system under test, providing both quantitate and qualitative assessments of performance to be made.
D662-8.2-C	• **Validation** ○ Validation activities should focus on acceptance and operational testing. ○ Where UxVs replace manned assets, physical testing against existing performance requirements may be made, especially for UUVs. ○ In support of approaches such as the NATO CD&E process, M&S methodologies may provide a route to bridge communities with the aim of stimulating the development of innovative systems and novel concepts of operation. ○ M&S methodologies may be employed to provide test evidence to support the validation of complex areas of operation, such as the performance of artificial intelligence systems.

8.3 Recommendations for the verification and validation of Unmanned System interoperability

This chapter discusses the key issues and factors considered during the development of improved unmanned system interoperability along with the verification and validation of the approaches.

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8.3.1 Aspect to consider

The lynch pin of interoperability is standardisation. However, in recent years, industry and organisations have developed systems working in complete isolation and, for example, many have introduced proprietary data models. As an example, this way of working has been the main barrier to interoperability in the underwater domain where little standardisation and few specifications have been adopted. The integration of interoperability first requires that a standard describing the technological products that are now achievable through the use of unmanned systems, including high resolution sensors and advanced processing. Lessons may be learn across the domains from the air domain which has advanced significantly in recent years. Additionally, in the spirit of reaching a unified multi-domain consensus, all domains should adopt the strategies applied in the air domain to generate and adopt STANAG 4586. STANAG 4586 describes the standard interfaces of UAV control systems for NATO. Within this, UAV interoperability promotes the use of five most relevant interoperability blocks:

- Launch and recovery
- The vehicle
- The payload
- Data link
- Vehicle control system

In reality, very little has been moved forwards to standardise these five pillars outside of the air domain. However, studies are progressing and some standardised approaches are being implemented, notably on the communications and data link aspects.

Integration, verification and validation should follow the principles laid out in section 8.1 of this report by defining and testing each functional block independently before culminating in system wide testing. In addition, M&S can be used as a powerful tool in the complete process from developing standards to the V&V testing of the final systems. During the development of standards, a range of M&S methodologies are particularly well suited to encouraging communication between the domain experts. This is often required to ensure that the resulting guidance is efficient, useful and achievable for the wide range of operational and technological variations that will be encountered in the design of multi-domain systems. Once these standards have been developed and adopted, M&S continues to offer methodologies that support the test and evaluation of the approaches in a range of harsh environmental conditions, covering natural meteorological and oceanographic challenges as well as analysing the impact of intentional electronic and cyber interferences upon the integrated system of systems.

For UAS interoperability, one of the most relevant standard is the STANAG 4586. This standard defines different level of interoperability (LOI) according to the control / monitoring that an external system can have on a given one. Due to the fact, STANAG 4586 cannot introduce strong constraints on system interfaces and exchanged data. Multiple implementations are then allowed and a high LOI can hardly be achieved. At short term, only low LOI should be

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reached. In the Med Sea Demo a two-dimensional example of interoperability was demonstrated during the boarding phase of the scenario that simulated the neutralization of a rogue mine-layer. UAV was in flight in the suspect vessel area, collecting data and video of the activities on board of the ship. When the fake mines were thrown off board, the E/O showed clearly the event at the MOCs and at the task force command ship that were receiving data streamed video. The order to neutralize the hostile ship was issued. One SH90 helicopter armed with machine gun and a RHIB with boarding strike team were ordered to take control of the vessel. While the striking team (SH90 and RHIB) were moving close to the target, they were both receiving UAV data and video on portable tablets. Therefore the two striking units were able to see the evolution of the situation on board of the target and decide in real-time the most effective attack tactics. According to STANAG 4586, this direct receipt of sensor product data constitutes the second level of interoperability (LOI2). The LOI2 was also demonstrated for USS since they were able to share directly their payload data (E/O) with the MOCs.

Although significant progress and achievements for Underwater Acoustic Networks have been made in recent years, one limiting factor has been the lack of standards for underwater digital communication. Several underwater digital modems are currently available on the market, none of these modems is however able to communicate with systems produced by other manufacturers. These vendor-locked solutions make the task of collaboration between different universities, industry and research institutes a difficult, if not impossible, one. Additionally, end-users and confronted with an increased acquisition risk since they need to commit to one single provider in order to have a working underwater communications system.

With this need for interoperability in mind, the NATO Science and Technology Organization (STO) Centre for Maritime Research and Experimentation (CMRE), in collaboration with academia, industry and National research laboratories dedicated several years of research into establishing a standard for digital underwater acoustic communications. The result of this was the recent promulgation of JANUS as a NATO Standardisation Agreement (STANAG 4748). JANUS is freely available online (www.januswiki.org) and can, therefore be used by anyone without restrictions.

CMRE has participated in the SCI-288 Research Task Group, organised by the NATO Collaboration Support Office, since 2015. This activity, titled “Autonomy in Communications Limited Environment”, has culminated in the design and implementation of a prototype interface to standardise interactions between autonomous systems for the purposes of collaborative mission execution. This message-based interface description was designed in 2018 and 2019, and was realised in software in 2019, when the partners involved integrated their institutional autonomy solutions with the messaging interface, allowing intra-vehicle collaboration using the SCI-288 interface. The integration, performed by CMRE, the United States of America (USA) (NSWC-PCD), the United Kingdom (GBR) (SeeByte Ltd). under contract from DSTL) and TNO from the Netherlands (NLD) , was demonstrated in a final workshop, held at CMRE from 21 - 30 October, 2019.

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For tethered ROV systems, the data processing files format (.XTF standard) and the mechanical interfaces required for ROVs to operate are heavily influenced by production and scientific underwater structures (mainly for heavy duty ROVs driven by oil & gas industry ISO IMCA standards).

In the First Simulated Trial of OCEAN2020 M&S was used to validate key underwater interoperability features, focussing not only on the sharing of data from UUVs, but also on other system interoperability pillars such the mission level effects of launch and recovery delays and the features offered by different vehicle and sensor types in a range of environments. Specific examples included the ability to show and compare the outputs from both autonomous UUV's with side-scan sonar and advanced on-board processing capabilities as well as ROV's that provide high bandwidth data in near real time. Further, the mission effects of adverse weather conditions on the launch and recovery of each of the underwater assets could be demonstrated and discussed. By demonstrating the effects of each of these interoperability pillars on the content of the MSA during the simulation of a complete scenario, existing OCEAN2020 interoperability requirements could be validated and discussed further with the operational community to develop an improved joint understanding of both the needs and opportunities of unmanned system interoperability.

Due to world-wide travel restrictions, the activities for the second simulated trial focused on the closer integration of simulation components from all domains into a centralised simulation toolset. In addition to this, the second simulated trial successfully built upon the features demonstrated in the first trial by expanding mission complexity and demonstrating key interoperability concepts. This was achieved by enlarging the number of cooperating assets, increasing the number of asset types and allowing collaboration between both surface and underwater assets in MCM missions. Specifically, mine search areas were divided between multiple systems, with MCMVs, USVs and UUVs searching geographically separated areas before reporting contacts into a central combat management system. The combined use of TNO and CMRE assets, as planned for the Baltic Live trial, was shown. This allowed their effects on the final mission outputs to be better understood.

In preparation for OCEAN2020's third simulated trial, M&S developments are under development that will further support the V&V of innovative interoperability solutions in the underwater domain. Specifically, the third simulated trial plans to integrate a representative collaborative MCM teaming algorithm in order to investigate the impact of scaling up the number of assets. This investigation will also identify key environmental parameters that may be considered when scaling up system assets in future deployments. In addition, a comparison of both UUV and USV architectures will be investigated in a mission that required the detection of objects in the water column. This comparison will allow domain specific interoperability resiliency aspects to be demonstrated and understood. As part of this comparison, system interoperability will be stressed by including periods of denied communication due to adverse environmental conditions and known asset limitations.

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8.3.2 Resulting recommendations for the Verification and Validation of unmanned system interoperability

An analysis of the wide-discussed recommendations for V&V activities related to the verification of unmanned systems are summarised in the following recommendations:

Recommendation number	Recommendation description
D662-8.3-A	The V&V of unmanned system interoperability should consider the five key pillars for Launch and Recovery, Vehicles, Payloads, Data Links and Control Systems.
D662-8.3-B	The V&V of unmanned system interoperability should follow the structured approach identified in 8.1 of this document.
D662-8.3-C	The advances made by the air domain, particularly in the adoption of STANAG 4586, should considered as a best practice example for the surface and underwater domains. The continued sharing of best practice from this standard may provide a framework for the V&V of interoperability across all domains.
D662-8.3-D	M&S methodologies provide an important route to aiding communication and joining communities to develop concept and user requirements, an important first step in the V&V of system interoperability.
D662-8.3-E	M&S methodologies provide the ability to carry out the V&V testing of each of the five key pillars of unmanned system interoperability, allowing the results to be understood by a wide range of stakeholders.
D662-8.3-F	In the underwater domain, the continued development and adoption of JANUS and SCI-288 may support future V&V activities.

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