Naval Autonomous Surface Vehicle Recoverability

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1 Synopsis

The ability to recover a vessel following an incident is a key part of Naval Survivability, be that due to equipment failure, accident, or hostile action. Recovery could require firefighting, flood control, re-instatement of damaged systems or more typically a combination of these. The recovery of the vessel is a key part of meeting requirements for continued operation of a vessel following damage and as such is intrinsically linked to a robust and persistent capability.

Historically recovery activities are heavily linked to personnel actions and have typically driven Naval vessel complements; what happens as we move towards autonomous vehicles? What is the requirement for recoverability of medium-large Autonomous Surface Vehicles and what are the goals we need to meet for vessel recovery? How does the comparative reduced cost, and higher number of these vessels, compared to today's multifunction warships, shift the balance for recoverability within the design?

2 Keywords

Autonomous Surface Vessels; Survivability; Recoverability

3 Biographies

Simon Bartlett is the Head of the Fire Section at the UK MOD, Naval Authority. He is responsible for fire certification of all 'MoD Shipping' and is actively looking at new and emerging technology in naval firefighting, damage control and recoverability. Simon has experience as an engineering officer in the RN and worked for the Fire Protection Association, as the Head of their Special Projects Group working on large scales fire trials for the defence and commercials sectors.

Ian Savage is the Chief Engineer for Transversals and Technical Assurance in BMT. Specialist in Naval recoverability he has undertaken engineering design and leadership particularly focusing on Naval Fire Protection and Damage Control on a wide range of Naval and Naval Auxiliary vessels.

4 Introduction

The requirements for Survivability and in this case recoverability on autonomous vessels is still in its infancy, with many people stating that it simply isn't required. As larger and more expensive Naval Autonomous Surface Vessels (NASVs) and/or remotely controlled vessels, continue to be developed to support mission payload requirements and blue water operations, consideration must be given to the ability of the vessel to recover from damage. This will enable it to either continue its mission independently / supporting a larger task group or at very least ensure it does not become a burden.

This paper aims to provide the goals and functional objectives against the 7 pillars of recoverability for NASVs, which provides the handrail for designs to achieve a recoverability solution appropriate for its size, cost, importance, and environment in which it operates, but always against a known baseline.

5 Overview of Recoverability

5.1 Survivability

Recoverability forms part of the larger discipline of Survivability which is 'The capability of a weapon system to continue to carry out its designated mission(s) in a combat threat environment' (NATO, ANEP-43, 2003). It is made up of the following key areas:

- Susceptibility – Avoiding detection, being targeted, or being hit by a hostile weapon.
- Vulnerability Reduction – minimise damage following a hit or accidental damage.
- Recoverability – Recover the capability of the vessel following damage or provide support to other vessels.

Figure 1 shows how recoverability interrelates with the other aspects of survivability, considering platform capability against time when subjected to a hostile threat. Recoverability can also be applied to equipment failure or accident, which will occur during a vessel's life and relates directly to the beginning of the Vulnerability phase in Figure 2.

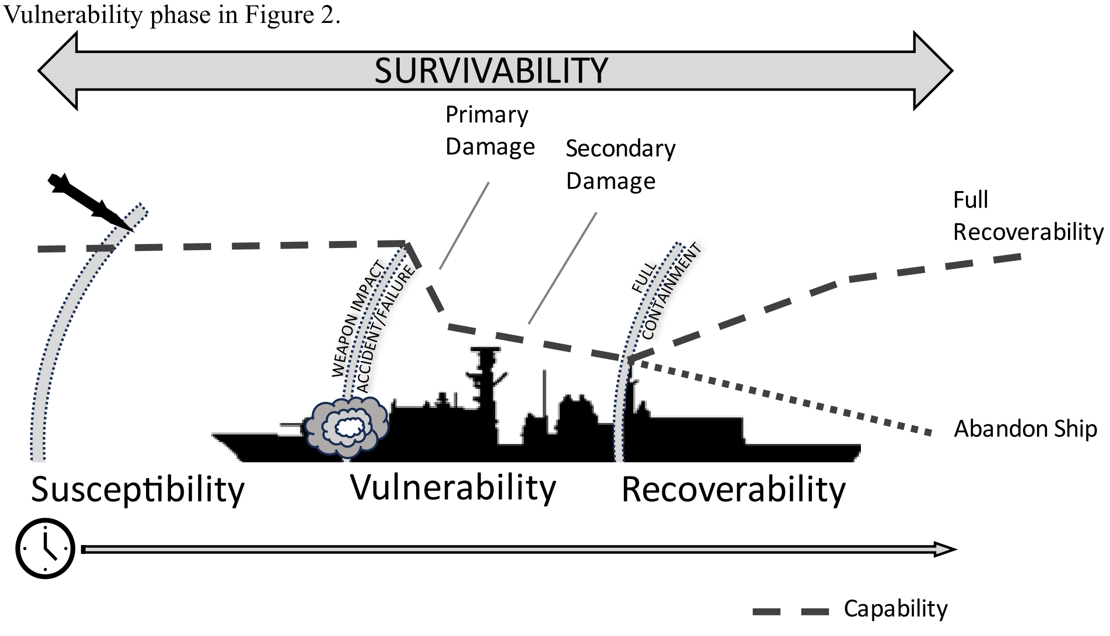

Figure 1 – Pillars of Survivability against Platform capability and time

5.2 Pillars of Recoverability

The ability to manage the recovery of a vessel is typically split into 7 areas, these are illustrated in Figure 2 and further described below.

Figure 2 - Pillars of recoverability

Situational Awareness – The collection, display and assimilation of information that provides the Command team with a clear understanding of the external threats, mission priorities, material state, ongoing incidents and existing platform defects linked to estimated times to repair.

Management – The effective co-ordination and prioritisation of recoverability activities to best meet the command aim utilising the available data, experience, knowledge and resources.

Containment – The ability to prevent the further loss of capability due to the spread of damage to unaffected areas and sections of the ship whilst also isolating potential sources of incident escalation.

Prosecution – The ability to limit the further loss of capability within the damage zone through aggressive action and resolution of a damage incident.

Recovery – The ability to provide resilience in system operation and means of restoring partial or full capability within specified timescales using predominantly onboard resources unless otherwise stated.

External Assistance – The ability to capitalise on external assistance from nearby units or shore-based support facilities to aid recoverability action while still in an area of high risk/threat. Conversely, the ability to render assistance to another unit or vessel that requires assistance.

Escape & Evacuation – The safe recovery of personnel from untenable spaces to a place of relative safety while maintaining the chain of command and mission priorities.

5.2.1 Human Interaction within Recoverability requirements

Delivery of recoverability is highly dependent on personnel to achieve recovery end goals within each pillar. To develop a NASV framework, each human delivered function, if still required must be automated. The following table provides typical personnel tasks within each pillar:

Pillar of Recoverability	**Human Interactions**
Situational Awareness	Boundary Searches / physical observations; Interpretation / confirmation of alarms and warnings, Casualty alarm, post incident compartment security.
Incident Management	Incident board updates; communications; incident response decision making and prioritisation; prioritisation of Command Aim; Incident section coordination; casualty management; Crew mustering.
Containment	Boundary temperature monitoring; Boundary cooling; Closing of doors, ventilation, and other openings; Shoring and leak stopping; closure of Watertight boundary valves.
Prosecution	Fast use of Stored Pressure Extinguishers; Continuous aggressive attack; Proportional directed operation of non-automated fixed firefighting systems; Manual firefighting techniques; use of portable pumps; operation of eductor systems.
Recovery	Damage Assessment; Capability Assessment; Machinery Repair; Mechanical and Electrical System reconfiguration.
External Assistance	Direct support to Damage Control activities either from or too other vessels.
Escape and Evacuation	Search and rescue activities from damaged areas of the vessel.

Table 1 – Human Interaction within recoverability

6 Do we need to Recover an NASV?

6.1 Why Recover a NASV?

There is a train of thought that NASVs are ‘disposable’ however, arguably this may be the case for small NASVs but as size increases a greater number of factors must be considered to ascertain the acceptable level of NASV recoverability:

- **Cost** – Whilst the monetary cost of a NASV is likely to be considerably lower than today’s complex warships, as size and complexity increases cost will still be significant, making loss less palatable due to minor accident or equipment failure, particularly in times other than war.

- **Threat environment** – the level of function that is required is linked to the threat environment, be that permissive, or non-permissive low to high levels. This will influence the risk to other vessels recovering a stricken NASV and potential drive different approaches to NASV recovery, this is further exemplified considering the difference between peacetime and combat operations.
- **Operation Capability** – Regardless of size, an operational asset contributes to the capability of the Task Group it is assigned and loss of that asset will reduce the capability of the Task Group. In some instances, e.g., for small sensorial enhancing NASVs, the loss may be tolerable, but as NASVs become more inherent to a role, e.g. task group pickets, the loss may become more difficult to account for whilst maintaining planned task group effectiveness and efficiency.
- **Legal culpability -** for the vessel and its actions.
- **Hazard to shipping** - potentially created by a disabled NASV.
- **Harm to the environment** - due to a disabled / damaged NASV.
- **Burden of casualty vessel recovery** – failure of, particularly, a medium to large NASV to recover from a defined level of damage is likely to result in recovery actions being required from the escorting vessels. If the NASV is acting as a singleton a specific recovery mission will be required. For example, larger NASVs that cannot be bought on-board a recovery vessel that therefore will require towing.
- **Operational security** – the NASV is likely to contain sensitive equipment, that could be retrieved from a stricken vessel. Should it become available to non-allied foreign nations it could result in a reduction in military advantage or risk the security of other military assets. This could drive requirements to skuttle the NASV or destroy sensitive equipment.

6.2 Is NASV Recovery size dependent?

The size of the NASV will limit the options for recovery based on the facility required to achieve recovery, in increasing size of NASV these are considered in Table 2:

Option	**Likely limiting factors to consider**
Simple recovery to a supporting vessel with minimal specialist equipment.	NASV Weight and access for crew on recovering vessel to the Waterline
Recovery to a supporting vessel with specialist equipment, e.g. bespoke davit / cradle.	Recovery equipment is bespoke to the vessel being recovered and the recovering vessel
Recovery to a supporting Landing Platform Dock (LPD) or equivalent dock equipped vessel	Dock sill and air draught limitations, and availability of LPD to Task Group
Recovery under tow. Effectively prohibiting the towing vessel from other operations and will limit manoeuvrability and responsiveness to threat.	Pickup of tow and/ or safe access to towing equipment on the NASV for crew to board and attach Tow. Loss of Task Group asset to conduct the tow.
Recovery by heavy lift ship.	Requires a vessel to be identified, contracted, deployed and a transit time to the casualty NASV before the vessel can be recovered.

Table 2 – Size - Vessel recovery consideration

Table 2 suggests that size needs to be considered against the capability of the Task Group to recover the NASV. Should either the capability not being available within the Task group or the operational penalty of recovering the NASV by another vessel be considered intolerable, then the NASV should be capable of self-recovery if the issues identified in section 6.1 are to be avoided.

7 Defining a NASV Recoverability philosophy

7.1 Approach

System importance and functional criticality is a consideration when reviewing recoverability prioritisation and provides clear indicators of areas that could warrant recovery of capability following damage to a vessel, to maintain safety to the vessel and other vessels, mission priorities, or limitations of threat to the environment.

In addition, owner culpability for the actions of the vessel requires a continued understanding of the state of the vessel, and what it is doing. This requires external communication to the vessel and confirmation that the command aim is active and being followed.

A review was undertaken of safety prioritisation of systems / functions within Lloyd Register Rules and Regulations for the Classification of Naval Ships (2023) (LRNSR), DNV Ship Rules, part 4 (2023), NATO Naval Ship Code, part 2 (2020) (NSC) and the IMO International Convention for Safety of Life at Sea (2020) (SOLAS) chapter 2-II, Regulation 21.

7.2 Classification and Regulatory System Function categorisation

LRNSR delineates systems into 3 types, excluding military systems:

- Ship Type, required to conduct its in-service purpose; operating and functioning of emergency machinery and equipment.
- Mobility, required for maintenance of Watertight integrity; safety and reliability of propulsion, electrical and steering, and operation and functioning of emergency machinery and equipment.
- Ancillary, systems other than Ship Type and Mobility

DNV Ship Rules, part 4, chapter 9 section 1.2 takes a different approach to the definition of control, monitoring, and safety systems into the following grouping, and by extension could be applied to systems as a whole:

- Non-Important- Failure will not lead to dangerous situations to human safety or vessel safety and /or threat to the environment.
- Important – Failure could eventually lead to dangerous situations to human safety or vessel safety and /or threat to the environment.
- Essential service and safety functions -Failure could immediately lead to dangerous situations to human safety or vessel safety and /or threat to the environment.

Safe Return to Port (SOLAS, Chapter II-2) or Maintain capability (NSC, Chapter VI) requires the maintenance of 14/17 (respectively) functions, following a defined level of flood or fire, to support safe operation of the vessel following an incident (non-hostile). Table 3 lists these functions and correlates them to NASV design:

In addition to functional requirements for system integrity for Maintain Capability / Safe Return to port, the NSC also structures itself around essential safety functions (ESFs), these are largely mirrored by the UK MOD's Defence Maritime Regulations for Health, Safety and Environmental Protection, DSA02-DMR (2022):

- Structure
- Stability, Buoyancy
- Engineering Systems
  1. Propulsion & Manoeuvring
  2. Power generation and distribution
  3. Machinery Control
  4. Alerts and Safety Systems
  5. Etc.
- Seamanship
- Fire Safety
- Escape and Evacuation
- Communications
- Navigation
- Dangerous Goods

Essential Functions	**NASV Applicability**	**Remarks**
Propulsion	Y	
Steering and steering control systems:	Y	
Navigation Systems	Y	
Fuel Oil and Lub Oil fill and transfer	Y	Dependent on Design
Internal communications to key control points	Y	Command data infrastructure
External Communications	Y	
Fire Main Systems	N	Not required unless for Fire extinguishing Systems
Fixed fire extinguishing	Y	
Fire and Smoke Detection	Y	
Bilge and Ballast	Y	
Power Operated Watertight Doors	N	Watertight boundaries should be set prior to departure
Safe Area (habitability) systems	N	
Flood detection	Y	
Damage Control Systems	Y	Should be split into specifics

Table 3 – Essential function NASV Applicability

7.3 Application to ASV recoverability

With the exception of DNV Ship Rules there are common threads running through the identification of safety related systems, e.g. propulsion, stability, and Fire protection and emergency systems, which already require additional attention through certification. Similarly, there are a number of common areas that are not relevant to a NASV, e.g. human habitability system, operation of critical WT closures at sea, internal communications, due to the lack of personnel on board. However, consideration does need to be given to the replacement of the 'human support systems' with machinery support systems, e.g. environmental management to maintain equipment operation, effective data communication pathways replacing internal communications.

The DNV methodology arguably offers a more useful '1st principles' approach demanding an assessment of each function or system of the vessel to identify its importance. The application of this forms a core set of ESFs that must be maintained and hence have a high level of recoverability, this is analogous to today's State 3 requirements for safe operations not under threat. The following table uses this approach against the relevant functional requirement for a safe return to port and shows allocation of a functional recoverability priority of high, medium or low.

Function	**Failure will not lead to danger**	**Failure could eventually lead to danger**	**Failure could immediately lead to danger**	**Functional Recoverability Priority**
Propulsion			Yes	High
Steering			Yes	High
Navigation			Yes	High
Command data infrastructure			Yes	High
External Communications		Yes	Yes (dependent on scenario)	High

Function	Failure will not lead to danger	Failure could eventually lead to danger	Failure could immediately lead to danger	Functional Recoverability Priority
Fire Extinguishing Systems		Yes		Moderate
Fire Detection		Yes		Moderate
Flood Detection		Yes		Moderate
Flood Management		Yes		Moderate
Environmental Control		Yes		Moderate

Table 4 – Essential Safety Functions priority

The introduction of mission system considerations, be that the specific systems or supporting systems moves this into State 1 requirements for operating under immediate threat. A similar view to that developed for ESFs was created for these systems, but with the focus being continued operational availability to continue the mission. This is shown in Table 5.

Function	Failure will not lead to Mission Impact	Failure could Degrade Mission	Mission Loss	Functional Recoverability Priority
Propulsion			Yes	High
Steering			Yes	High
Navigation			Yes	High
Command data infrastructure		Yes	Yes	High
External Communications		Yes		Medium
Fire Extinguishing Systems			Yes	High
Fire Detection		Yes		Medium
Flood Detection		Yes		Medium
Flood Management			Yes	High
Environmental Control		Yes		Medium
Mission Equipment				Based on CONOPS

Table 5 – Mission Systems functions priority

7.4 What level of Recoverability (Weapon and accidental) do we need

Recoverability functions need to demonstrate benefit to be adopted on an NASV, as such a hierarchy of the application of recoverability functions should be observed as follows:

- Essential Safety Functions – these relate directly to those areas where failure could lead immediately to danger to 3rd parties and should be applied to all vessels.
- Mission Loss Functions- these related directly to those areas where failure could lead immediately to mission loss and should be applied where required by the Concept of Operations (CONOPS) to ensure mission requirements can be met.
- Delayed safety or mission Functions – should be subject to cost benefit analysis at design, this will allow a balance of cost/ safety/ mission to be ascertained, based on a level of specific risk and operational requirements, whilst maintaining minimum levels of safety within the design.

8 NASV Recoverability philosophy

8.1 NASV Recoverability Goals

NASV recoverability goals have been developed considering the above philosophy and the existing recoverability goals for crewed vessels, presented in *Maritime Acquisition Publication 01-127, Warship Recoverability* (2013); some goals remaining unchanged, and others changing more fundamentally. Table 6 shows the new goals and their related functional areas that are further developed in section 8.

Escape and Evacuation has been removed as it is no longer considered relevant to the NASV. However, there are some exceptions where this may still be required, should personnel be required to board the NASV at sea for any reason.

Pillar	Recoverability Goal	Related Functional Objective Domains
Situational Awareness	The command team and ship control system to have the required knowledge and understanding of the mission priorities, the platform state and evolving damage picture so that actions taken to contain, prosecute and where possible recover from damage is timely, effective and does not further degrade safety or mission capability.	Command Aim Data Collection Redundancy Readiness States Remote Picture Compilation
Management	The effective use of information for the interpretation, prioritisation, and implementation of recoverability either via onboard control system(s) or offboard command centre.	External Communications Decision Making and Priorities
Containment	Facilitate containment of damage to the smallest footprint, and the management of incident boundaries enabling effective damage control and recovery if available.	Isolation Boundaries
Prosecution	Facilitate an effective response to prevent further loss of capability, or real estate beyond that caused by the initial incident. Due to the potential of being constrained by system design or coverage, prioritisation of the incident response may need to be considered.	Fire Flood Stability
Recovery	Design features that provide resilience in system operation and means of restoring partial or full capability within specified timescales using onboard systems unless otherwise stated.	Reconfiguration Machinery Redundancy Mission Sustainability Smoke Management Dead Ship
External Assistance	The ability to safely receive external assistance to maintain capability or recover the vessel shall be considered to prevent minor defects or known single points of failure removing the capability prematurely. This may be addressed by support vessels, task group support or by allied interoperability.	Advice Resource Repair Emergency Recovery

Table 6 – NASV recoverability Goals

9 NASV Recoverability Functional Framework

Having identified a philosophy to apply to NASV recoverability and the associated goals, functions to deliver the philosophy can be amended and summarised in Table 7. Additionally, application of the philosophy presented in section 7 is appended to demonstrate the value of each function relating ESFs and mission.

Recoverability Pillar	Functional Objective Title	Functional safety Functions / *Mission Functions*	Related Essential Safety Function	Essential Safety Failure could….			Mission Capability		
				Not lead to danger	Eventually lead to danger	Immediately lead to danger	No Impact	Degraded	Mission Loss
Situational Awareness	Command Aim	Enable the command aim to be disseminated from command operation centre to vessel and fully understood in terms of system configuration and incident priorities. The design must incorporate the means to achieve this effectively, quickly and with sufficient detail that recovery timescales are kept to a minimum. Commanding Officers or Command Systems are responsible for determining the balance between preventing a danger to third parties; protecting their vessel and projecting military capability, the following principles are to be observed: a. At Sea. Maintain a safe vessel that does not pose a danger to any third party. *b. On Operations. Maintain effective military capability.*	-External Communications -Command Data Architecture		Y			Y	Y
Situational Awareness	Data Collection	Design that provides accurate and timely data on ship state, systems, and damage mechanisms to command nodes to be integrated into the internal battle picture. To include but not be limited to: a) Fire Detection b) Flood Detection: 1. System Leakage 2. Flooding c) Internal environment (pre/during/post incident) d) Ships Integrated Chemical or Radiological System e) System parameters (Pre/post event monitoring) f) External emissions monitoring (Leakage, noise, pollution)	-Command system and data infrastructure -Fire Detection -Flood Detection -Environmental Control -Propulsion -Steering -Navigation -Other Function/Safety related Marine Systems		Y			Y	

Recoverability Pillar	**Functional Objective Title**	**Functional safety Functions / *Mission Functions***	**Related Essential Safety Function**	**Essential Safety Failure could….**			**Mission Capability**		
				Not lead to danger	**Eventually lead to danger**	**Immediately lead to danger**	**No Impact**	**Degraded**	**Mission Loss**
Situational Awareness	Redundancy Readiness States	Design permits essential safety systems redundancy states: a) Safe transit navigation b) Task Group manoeuvres c) Confined waters navigation d) Harbour states e) Reduction in situational awareness due to severe weather/ equipment failure. *Design permits system redundancy states to support the mission essential equipment in a non-permissive environment including:* *a) Equipment support the Command aim* *b) Evasive manoeuvres to a known threat* *c) Military systems operation in accordance with the CONOPS.*	-Propulsion -Steering -Navigation -Other Function/Safety related Marine Systems			Y			Y
Situational Awareness	Remote Picture Compilation	Design enables data to be displayed in real time, in a manner that can be rapidly and accurately assimilated by the remote command team or remote system thus allowing assurance that onboard system control is making the right decisions in the form of a command veto. This is important for 3rd party risk and MOD culpability.	-Command system and data infrastructure			Y		Y	
Management	External Communications	Design enables: a) Communication of immediate danger to 3rd parties. b) Relay of external safety communications, e.g. MAYDAY, to Command, SOLAS responsibility c) Redundant external communication paths to permit continued internal situational awareness pre/during/post incident, system configuration, command veto / remote intervention of safety / emergency system operation. *Design enables communication of mission capability risk or failure.*	-External Communications			Y		Y	

Recoverability Pillar	**Functional Objective Title**	**Functional safety Functions / *Mission Functions***	**Related Essential Safety Function**	**Essential Safety Failure could….**			**Mission Capability**		
				Not lead to danger	**Eventually lead to danger**	**Immediately lead to danger**	**No Impact**	**Degraded**	**Mission Loss**
Management	Decision Making and Prioritisation	Design enables the remote command team or internal system control system to reach an informed, timely and reliable decision and implement actions required to achieve the command aim. An internal control system must have the ability to prioritise recoverability actions to best meet the command aim.	-Command system and data infrastructure			Y			Y
Containment	Isolation	Design enables potential sources of incident escalation to be removed through system isolation. Arrangements and operation of system isolations must be considered carefully to ensure they can be operated effectively in all scenarios.	-Propulsion -Steering -Other Function/ Safety related Marine Systems		Y			Y	Y
Containment	Boundaries	Boundaries (smoke boundaries, fire boundaries, and watertight integrity) must be designed to meet the vulnerability and recoverability functions to allow the vessel to maintain its ESFs. Mission functions will be included if required by the Concept of Operations.	-Fire and Flood Protection		Y			Y	
Prosecution	Fire	Design to enable fires to be controlled and proven extinguished to reasonably minimise fire damage and to protect ESFs. Selection of firefighting systems to allow continued protection of casualty compartments post fire. Firefighting systems to be selected to have minimal effects on protected systems and stability. *Mission Systems shall not present a fire risk to ESFs, and if required by the CONOPS shall be subject to fire protection measures. Mission systems should not be damaged by fire protection system operation, e.g. Ingress Protection rating of enclosures.*	-Fire Protection		Y			Y	

Recoverability Pillar	**Functional Objective Title**	**Functional safety Functions / *Mission Functions***	**Related Essential Safety Function**	**Essential Safety Failure could….**			**Mission Capability**		
				Not lead to danger	**Eventually lead to danger**	**Immediately lead to danger**	**No Impact**	**Degraded**	**Mission Loss**
Prosecution	Flood	Flooding due either to external hull damage or internal system failure shall be controlled to reasonably minimise flood damage and to protect ESFs. *Mission Systems shall not present a flood risk to ESFs. Flooding due either to external hull damage or internal system failure shall be controlled to reasonably minimise flood damage and to protect mission systems as required by the CONOPS.*	-Flood Management		Y			Y	
Prosecution	Stability	Design to ensure that an acceptable level of stability can be maintained throughout recovery and may require the ability to rapidly transfer, remove fluids or recover buoyancy where possible. Firefighting media will be managed to limit top weight and free surface moment during firefighting.	-Flood Management		Y			Y	
Recover	Reconfiguration	Systems delivering ESFs to be operated partially or fully with alternative supplies, or in different modes to allow reconfiguration and recovery of the system if required, or to support change over to redundant systems. *Internal control systems shall be able to detect faults or system battle damage, reduce the consequence through system isolation and reconfigure systems to quickly restore functionality that supports the command aim.*	-Propulsion -Steering -Navigation -Other Function/Safety related Marine Systems			Y			Y
Recover	Machinery Redundancy	Where recoverability of ESFs cannot be achieved additional redundancy shall be provided to ensure recoverability targets can be met. *Where recoverability of essential mission functions cannot be achieved design should enable battle overrides of mission essential equipment.*	-Propulsion -Steering -Navigation -Other Function/Safety related Marine Systems -Mission Equipment		Y			Y	

Recoverability Pillar	**Functional Objective Title**	**Functional safety Functions / *Mission Functions***	**Related Essential Safety Function**	**Essential Safety Failure could….**			**Mission Capability**		
				Not lead to danger	**Eventually lead to danger**	**Immediately lead to danger**	**No Impact**	**Degraded**	**Mission Loss**
Recover	Mission Sustain-ability	Systems delivering ESFs shall be designed with sufficient redundancy to allow systems to be tolerant of minor system defects and allow sustained missions to be completed, without external assistance or emergency recovery.	Mission Equipment	Y					Y
Recover	Smoke Management	Smoke shall be managed to minimise its effects on ESFs, maintain internal situational awareness and to minimise risk of further fire spread. *Smoke management arrangements should allow continued operation of Mission Systems. Smoke management priorities shall be considered to avoid adverse impact on the Command aim.*	-Command system and data infrastructure -Fire Detection -Flood Detection -Environmental Control -Propulsion -Steering -Navigation -Other Function/Safety related Marine Systems		Y			Y	
Recover	Dead Ship	The ship shall be able to recover from a total loss of power. Systems delivering ESFs shall be provided with immediate stored energy backup. *Mission Systems shall be provided with immediate stored energy backup.*	-Propulsion -Steering -Navigation			Y			Y
External Assistance	Advice	System (machine) learning of all permutations of damage is unlikely to be viable, the design shall be capable of seeking timely Command instruction, confirmation of action or veto when faced with damage situations beyond the current trained scenarios.	N/A	Y	Y			Y	

Recoverability Pillar	**Functional Objective Title**	**Functional safety Functions / *Mission Functions***	**Related Essential Safety Function**	**Essential Safety Failure could….**			**Mission Capability**		
				Not lead to danger	**Eventually lead to danger**	**Immediately lead to danger**	**No Impact**	**Degraded**	**Mission Loss**
External Assistance	Resource	Enable the safe and effective transfer of equipment and personnel where practicable onto the vessel, over the deck, and within the vessel. The vessel shall understand when personnel are onboard and provide audible warnings if ship actions or internal environment could provide a risk to life.	N/A	Y				Y	
External Assistance	Repair	Critical defects or known single points of failure shall be accessible for rectification at sea, maintaining safe routes of access and escape. Where practicable this should be achievable via weather deck access only.	N/A	Y	Y			Y	
External Assistance	Emergency Recovery	The vessel shall have the capability to be towed to a safe location to aid in safe navigation of other vessels or to support restoration of capability. *Consideration of remote scuttling of the vessel to deny the asset, its weapons or restricted technology to 3rd parties.*	N/A	Y				Y	

Table 7 – NASV Recoverability Functions Summary

10 Conclusions

Definition of recoverability requirements for NASVs is complex due to a combination of safety, mission, task group burden and role and it is not appropriate to simply apply existing recoverability philosophy to an NASV. However, as a minimum a set of recoverability requirements must be applied to ensure recovery of functions to safeguard 3rd parties following though either accident, equipment failure or defined levels of hostile damage. Functions leading to degraded mission or safety performance should be balanced against cost benefit and offer a potential trade space that is specifically tailored to the role and size of the vessel.

10.1 Next Steps

This paper has presented a set of building blocks for a safe and capable autonomous vessel. The realisation of (particularly larger) NASV requires consideration of key technology and the definition of their requirements around the functional objectives identified herein. This should allow preferable system technologies to be identified for use onboard NASVs and other autonomous vehicles.

As part of this and to support the specification of vessels a sliding scale of vessel recoverability requirements based on the goals and functional objectives defined in the paper should be developed to match the CONOPS for the vessel taking account of vessel cost, threat environment and function of NASV.

11 References

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12 Glossary

ANEP	Allied Naval Engineering Publication
AI	Artificial Intelligence
ASV	Autonomous Surface Vessel
CONOPS	Concept of Operations
DMR	Defence Maritime Regulator
DSA	Defence Safety Authority
ESFs	Essential Safety Functions
IBC	Internal Battle Co-ordinator / Damage Control Officer
IMO	International Maritime Organisation
LPD	Landing Platform Dock
LRNSR	Lloyds Register Naval Ship Rules
MAP	Maritime Acquisition Publication
MOD	Ministry Of Defence
NASV	Naval Autonomous Surface Vessel
NATO	North Atlantic Treaty Organisation
NSC	NATO Naval Ship Code
SOLAS	International Convention for the Safety Of Life At Sea
SQEP	Suitably Qualified and Experienced Person
UK	United Kingdom