National Oceanography Centre (NOC) – Written evidence (AUV0056)

Summary:
The UK is a global leader in the development and deployment of Marine Autonomous Systems. These systems are very well suited to a range of maritime activities including survey, sustained observations, patrol and monitoring, pollution response, pipeline inspection and a range of defence applications. Marine Autonomous Systems offer considerable cost savings over the use of a ship with a human crew (particularly the long-range systems that do not require a ‘mother ship’), can be operated in hazardous waters or under ice without risk to life, and can be operated if necessary in large numbers. They do not yet have sufficient dexterity or artificial intelligence to carry out all of the operations of a ship with a human crew, but future advances will lead to constant improvement in capability.

There are considerable gaps in insurance, regulation and legislation in the UK and international maritime law that can present formidable challenges to ‘early adopters’ of this technology, but the user community is working together to produce Codes of Conduct and recommendations to international bodies. There is potential for wealth creation from the development and use of Marine Autonomous Systems (including conversion of existing ships to autonomous operation) and there is also potential to grow the supporting insurance, licensing and training sectors.

Very few modifications are required to existing infrastructure.

Introduction
Recognising that the main thrust of this inquiry concerns driverless land vehicles, the National Oceanography Centre submits for your consideration responses to the Committee’s questions that reflect the wider implications of autonomy in a marine context, as it is an area of science, engineering and technology where the UK is at the forefront of global developments and where we are recognised as leaders in the field.

There are many cross-cutting issues that are of equal concern to land, air and sea-based autonomous systems, including the legal regime under which they operate, licensing, insurance, and especially the need to avoid collision or interference with human-occupied vehicles.

The National Oceanography Centre is wholly owned by the Natural Environment Research Council www.nerc.ac.uk and is based at sites in Southampton and Liverpool. NOC is NERC’s centre of excellence for oceanographic sciences with a remit to provide leadership and national capability in the marine sciences from coast to deep ocean. Since the late 1980s at our predecessor institution the Institute of Oceanographic Sciences Deacon Laboratory, through to today’s National Oceanography Centre, UK scientists and engineers have pioneered the design, construction and deployment of advanced Marine Autonomous Systems, surface and sub-surface, self-propelled or drifter, and we remain global leaders in the real-world application of autonomy, and the development of appropriate safe systems of work and governance mechanisms.
Responses to Questions

1. What are the potential applications for autonomous vehicles? –

1.1 In the maritime context, autonomous vehicles (sub-surface or surface-based) have been deployed since the 1990s to perform a variety of duties including:

- Data acquisition for marine scientific research
- Fisheries research
- Defence applications
- Pollution monitoring
- Surveillance and reconnaissance
- Seabed survey
- Pipeline inspection
- Surveys in dangerous or hard-to-reach waters such as underneath ice caps or mid-winter storms.

Note that the marine user community is settling on the term ‘Marine Autonomous Systems’ (MAS) to define the unmanned vehicles/platforms and free-roaming sensors that operate at sea, with subdivisions into surface (MAS-S) and underwater (MAS-U) types, and these terms will be used through the rest of this submission. The acronyms AUV (Autonomous Underwater Vehicle) and USV (Unmanned Surface Vehicle) are commonly used by the community.

1.2 In the near future it is reasonable to envision the everyday use of Marine Autonomous Systems of increasing size and sophistication to undertake duties that are currently performed by human occupied platforms such as workboats, cargo ships and warships, subject to updated marine safety legislation, licensing of operators, insurance cover, redundancy of systems, appropriate Rules of Engagement (for military users) and the level of on-board artificial intelligence. The carriage of passengers is far less likely in the short term due to safety requirements in case of emergency.

1.3 Small, relatively inexpensive Marine Autonomous Systems are particularly well-suited to tasks that require repeated observations of clearly defined parameters such as seawater physical and chemical properties, measurement of underwater sound, monitoring security or checking integrity of structures at sea over a sustained period. Having much lower operation costs than a research or survey-class vessel with crew, extended duration operations or a denser network of sampling become affordable, and would for example help the UK meet any obligations that arise from national, European and international marine environmental protection treaties, laws and conventions. For example, long-range Marine Autonomous Systems (Surface) could patrol Marine Protected Areas in British Overseas Territories at a small fraction of the cost of crewed vessels, particularly as endurance and reliability of systems improves, and through use in conjunction with satellite or aerial remote sensing.

1.4 Marine Autonomous Systems are excellent platforms for observations in hazardous or severely polluted waters and during extreme weather conditions where a conventional ship would have to seek shelter or heave-to until wave conditions subside.
1.5 For a surface vehicle, use without crew but without autonomy (i.e. by remote control from shore or mother ship) is relatively straightforward to implement, as ships have plenty of on-board power for communication systems, few weight or space restrictions, and compared with a land or air vehicles low velocities and some degree of flexibility in decision response time. Remote control of ships has been tested for specialised purposes such as mine clearance. Full size cargo ships could operate in the High Seas in autonomous or remote control mode, and receive a human crew as they approach coastal waters, marine protected areas, fragile ecosystems or more crowded waters.

1.6 Marine Autonomous Systems (Underwater) – widely known as AUVs within the industry, (for Autonomous Underwater Vehicles) are usually unable once submerged to use radio frequencies to maintain contact with a human operator and in most cases operate in fully-autonomous mode, requiring human intervention only at the start and end of a mission for deployment and recovery. It is possible to establish a data link with a vehicle once it is on the surface to update mission parameters or download low-bandwidth data, but for the majority of the time a Marine Autonomous System (Underwater) has to operate according to the pre-programmed mission subject to modification according to hazards or obstacles encountered and the level of artificial intelligence that is available.

1.7 As a consequence of having to operate without human intervention, Marine Autonomous Systems (Underwater) require sophisticated obstacle avoidance, reliable and redundant systems, the ability to self-diagnose faults and if necessary surface or return to base if a fault or low-power state is detected. In complex 3 dimensional environments such as underneath ice sheets that have a solid ‘lid’ above, the vehicles require skilled programming and sufficient artificial intelligence to navigate their way past obstacles that are not pre-determined on charts, and for military systems there are additional requirements for stealth and self-protection.

2. What are the potential user benefits and disadvantages from the deployment of autonomous vehicles?

2.1 The greatest benefit from a maritime context is cost-saving compared to the use of a conventional ship with crew – though this is less so for short-range vehicles that still require a ‘mother ship’ for deployment, recovery and data download. Even short range Marine Autonomous Systems act as ‘force multipliers’ enabling a survey ship, research vessel or naval platform to gather data over a considerably increased area than it could do solo, or for the ship to ‘stand-off’ while the autonomous system carries out a hazardous task such as under-ice survey, or inspection of a wreck or hazardous object.

For long-range Marine Autonomous Systems, it can be possible to avoid the use of a ‘mother ship’ altogether, launching and recovering the vehicle from the shore, offering very considerable savings for long-term sustained observations in the marine environment by civilian, industry, research and defence users.

Due to the cost saving, the other major benefit that arises is the ability to increase the number of vehicles that can be deployed within the available budget. This increases density of observations and availability of data, and allows some level of redundancy if a system fails or is lost to natural hazards such as winter storm or entrapment in ice or fishing gear.
2.2 The National Oceanography Centre has already demonstrated the advantages of long range marine autonomy without a ‘mother ship’ with our Autosub Long Range vehicle, and with Marine Autonomous Systems (Surface) directly deployed from coastal locations such as the Isles of Scilly.

2.3 Smaller size than a conventional ship or submarine offers cost savings, but also enables a Marine Autonomous System to reach places and carry out tasks that are difficult for a full-size vessel, for example exploration of confined underwater spaces, operations in very shallow waters, operations in ultra-deep waters, and operations under ice. For defence users small size offers considerable benefits for systems that are used in a surveillance and reconnaissance role.

2.4 Drawbacks – There is still no full substitute for the human eyeball, brain and hands and until we have ‘true’ artificial intelligence, which may become available in coming decades, there will always be limitations to the tasks that can be assigned to Marine Autonomous Systems. The smaller platforms also have limited payload space, limited on-board energy compared with a ship, and are vulnerable to hijacking or theft by unscrupulous or criminal elements at sea.

2.5 Lacking complicated ‘manual handling’ systems limits the number of samples that could be taken and stored on board. There is no ability to repair even simple equipment failures such as a blocked pipe or water inlet, and for missions that need to interact with living creatures an autonomous system is far from capable of catching, retrieving and humanely analysing a fish – it will be many years before a robot can do such a thing, though with a sufficiently advanced telemetry system and virtual arms some tasks may be possible from a shore–based operator by remote control instead of autonomy.

2.6 Marine Autonomous Systems (Surface) can offer real-time video feed to human operators, but real-time communication is generally not available for underwater systems, unless the system is close to a parent vessel and ‘tethered’ by optical fibre or acoustic datalink.

3. Are further revisions needed to insurance, regulation and legislation in the UK to create an enabling environment for autonomous vehicles?

3.1 Yes - the current national and international laws and customs of the sea did not evolve in the expectation that robots would one day roam the oceans, and there are substantial gaps - often an absence - of legislation regarding the use of Marine Autonomous Systems – see 3.9 below. For example when seeking advice from the UK’s Marine Management Organisation (MMO) as to whether we require a licence to deploy Marine Autonomous Systems, MMO staff have needed to make decisions through extrapolation of existing laws that apply to ships, and so have regarded our Autonomous Underwater Vehicles so far as ‘vessels’ – yet an autonomous ‘vessel’ has no bridge watch-keeper or lookout, cannot render assistance to a sailor in distress, may lack a Port of Registry and could potentially not carry any insurance.

3.2 NOC and our marine science partners have evolved safe systems of work that include cooperation with the Marine and Coastguard Agency, Royal Navy and Hydrographic Office to
issue Notices to Mariners, and liaison with fishermen and coastal communities in our areas of operation to educate the public. Basic actions include writing 'Harmless Scientific Instrument' in bold letters on the hull, the use of bright paintwork, flashing beacons and contact telephone numbers and email addresses so that if a vehicle is encountered by a marine or coastal user they can quickly confirm the non-hazardous nature and ownership of our vehicles.

3.3 In March 2016 the UK Marine Industries Alliance (MIA) launched the first industry Code of Conduct in respect of Marine Autonomous Systems (Surface), with the long term aim of establishing a pan-industry agreement in respect of the development, design, production and operation in advance of, and alongside the eventual establishment of governing regulations. It is a comprehensive Code of Conduct that covers industry responsibilities, health and safety, environment, product safety, design and construction, identification of the systems on the surface, assurance certification and authorisation for use, trade restrictions and export controls, operational responsibilities, regulatory and legislative compliance and training and development. The code can be viewed and downloaded at [http://asvglobal.com/wp-content/uploads/2016/03/UK-MIA-MAS-CoC-2016.pdf](http://asvglobal.com/wp-content/uploads/2016/03/UK-MIA-MAS-CoC-2016.pdf)

3.4 So far the lack of legislation has not substantially prevented the use of systems in a research context, and some potential military applications of Marine Autonomous Systems are by their very nature clandestine, but as the numbers, diversity of users, and especially the size of Marine Autonomous Systems increases, it can be expected that eventually a collision or other event will occur that endangers property and life, particularly if operators do not adhere to the recommendations of the Code of Conduct mentioned in 3.3.

3.5 As the sector grows, new or revised regulations are required to govern the safe operation of Marine Autonomous Systems (Surface) in particular – for submerged systems there are relatively few hazards to other users of sea space, except for operators of submarines or seabed equipment that could potentially be damaged by collision with one of the larger autonomous vehicles. However, conflict with fishing gear is a hazard, and larger vehicles could be of sufficient mass to endanger smaller classes of fishing vessel - for example Boeing’s 2016 ‘Echo Voyager’ AUV is 51 feet long and weighs 50 tons.

3.6 As the application of marine spatial planning continues to evolve across the world (e.g. in the UK the systems that are arising out of the Marine and Coastal Access Act (2009) and Marine (Scotland) Act 2010) there will be an opportunity to help ensure that autonomous underwater vehicles can be operated without fear of entanglement in fishing nets, which is the primary hazard currently faced by these systems, and to ensure that safe separation of operations can be carried out, for example by Marine Autonomous Systems engaged in survey work, marine science and environmental monitoring.

3.7 The UK’s pioneering community of Marine Autonomous System users (who include the National Oceanography Centre, the Scottish Association for Marine Science, the Society of Maritime Industries, Royal Navy and manufacturers of marine autonomous systems) have helped place the UK in the global lead for autonomy at sea, and are well placed to work with the Marine Management Organisation, Marine Scotland, Ministry of Defence, Marine and Coastguard Agency, Trinity House, Hydrographic Office and Marine Science Coordination.
Committee to help ensure that the UK has fit for purpose legislation and can liaise with international regulatory and marine science bodies to help our Best Practise become the industry standard across the world.

3.8 At International Bodies such as the Intergovernmental Oceanographic Commission of UNESCO and International Maritime Organisation the UK is seen as the ‘champion’ for Marine Autonomous Systems and is in position to help develop next-generation maritime legislation.

3.9 There is already some international experience in the global operation of Marine Autonomous Systems, mainly in the field of Marine Scientific Research. Since the 1990s Marine Autonomous Systems in the form of over 3000 ‘Argo’ floats (unguided small oceanographic instruments that drift freely on ocean currents, undulating between the surface and several thousand metres depth, collecting science data and transmitting to shore every few weeks when on the surface) have played a vital role in helping the international marine science community to advance their knowledge of the three dimensional structure of the global ocean, and its temperature, salinity and other parameters.

Argo operations that take place within the Exclusive Economic Zones (EEZ) of Sovereign States use the provisions of Part XIII (Marine Scientific Research) of the UN Convention on the Law of the Sea (see Article 247 of the Convention, assisted by IOC-UNESCO Resolution XX-6 and others).

Where floats (i.e. small Marine Autonomous Systems that drift on ocean currents or with the prevailing wind) are deployed in international waters, and begin to drift towards an EEZ, prior notifications are made to the relevant Sovereign State, because it is not possible to change the direction in which the float is travelling. A Sovereign State has the right to request that sensors on an Argo float are switched off while it transits their waters, or that data is not transferred to a public domain until they have reviewed the content. So far most countries have accepted the routine measurement of temperature, salinity and pressure within their EEZ without question but as more advanced sensors become available that measure biogeochemical and other parameters the situation becomes far more complex – a State can legitimately demand 6-months prior notice that a Marine Autonomous System is due to enter their waters, and has the right to refuse entry.

With a system that has a degree of control over navigation and the ability to regularly communicate with a shore base, these legal issues can be easily resolved and a diplomatic incident avoided, but a Marine Autonomous System that is submerged and out of contact, or has no propulsion system and is unable to navigate freely, or has suffered mechanical or communication system failure, may drift into waters without permission, and trigger undesired consequences. As Marine Autonomous Systems become commonplace, performing a wide range of tasks, new international legal instruments will be required to ensure safe and legal operation in both international waters, and within EEZs.

The UK, as a global hub of expertise in maritime and shipping law, is well-placed to play a leading role in the development of new statutory and voluntary instruments.
3.10 In our experience the Marine Professional Bodies and Learned Societies the Institute of Marine Engineering, Science and Technology (IMarEST) and Society for Underwater Technology (SUT) have been valuable allies in helping to develop Marine Autonomous Systems, build links across the user community and propagate best practise in the safe and reliable use of these vehicles.

3.11 Clusters of users are beginning to emerge and share their experiences, conferences on use of Marine Autonomous Systems such as the NOC Marine Autonomy and Technology Showcase scheduled for 14-18 November 2016 are taking place, and a new NERC/EPSRC Centre for Doctoral Training in Next Generation Unmanned Systems Science will help ensure a supply of well-trained experts in the field.

3.12 Unlike a ship with a crew, there are no obligatory statutory requirements for people who deploy and operate Marine Autonomous Systems to be certified, licensed or qualified to an agreed international standard. Whilst such systems exist in small numbers, and are operated by expert specialist users this is not causing a problem, but as the number and physical size of systems and breadth of duties increases there will come a point where some form of licensing becomes a necessity for continued safe operation.

3.13 Insurance requirements are also not defined for Marine Autonomous Systems, though to date users who wish to do so have been able to obtain insurance cover from a specialist insurers based in London – in time this could develop into a significant market.

4. What is the scale of the market opportunity for autonomous vehicles?

It is hard to estimate how large the market for Marine Autonomous Systems will eventually be, but it is reasonable to assume it will be large enough to sustain a viable export-focussed industry.

Cargo ships are well-suited to at least partially autonomous operations, either as retrofit to existing ships or incorporated from the start with new designs. Such ships may operate as a convoy in company of a human-crewed mother ship, or autonomously.

Passenger vessels are unlikely to be fully autonomous, though as artificial intelligence systems mature the ship’s ‘mind’ may eventually be intelligent enough to take over the day to day duties of sailing the vessel and looking after various services and functions.

Supporting services such as insurance, training and licensing of operators all offer potential as growth markets for the UK.

5. Will successful deployment of autonomous vehicles require changes to digital or physical infrastructure?

Deployment of increasing numbers of Marine Autonomous Systems may require minor modifications to port and harbour facilities, particularly for large autonomous cargo vessels, to ensure safe docking without human intervention.
Fully autonomous underwater vehicles will benefit from seabed or moored refuelling and data download docking stations, and the provision of acoustic navigation grids that function in an underwater environment – this could be possible in certain applications such as patrol of a seabed carbon storage facility, monitoring the decommissioning of large-scale oil and gas infrastructure, or a fixed deep-sea aquaculture location.

Current satellite navigation systems are adequate for surface vehicles but are not available to submerged systems (because most radio frequencies cannot penetrate underwater) unless the vehicle or sensor has some form of datalink to the surface, such as a towed buoy.

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Acronyms used:
AUV Autonomous Underwater Vehicle
EEZ Exclusive Economic Zone of a Sovereign State
EPSRC Engineering & Physical Sciences Research Council
IMarEST Institute of Marine Engineering, Science & Technology
MAS Marine Autonomous Systems
NERC Natural Environment Research Council
NOC National Oceanography Centre
SUT Society for Underwater Technology
UNESCO United Nations Education, Scientific and Cultural Organisation
USV Unmanned (or un-crewed) Surface Vehicle