Rolls-Royce – Written evidence (AUV0083)

Introduction
Rolls-Royce designs, develops, manufactures and services integrated power systems for use in the air, on land and at sea. We are one of the world’s leading producers of aero engines for large civil aircraft and corporate jets and the second largest provider of defence aero engines and services in the world. For land and sea markets, reciprocating engines and systems from Rolls-Royce are in marine, distributed energy, oil and gas, rail and off-highway vehicle applications. In nuclear, we have a strong instrumentation, product and service capability in both civil power and submarine propulsion.

In the UK Rolls-Royce employs c23,000 people, including 9,000 engineers – more than half of our global engineering resource - and 95%+ of our people are based outside London and the South East. Recent investments in the UK include new manufacturing facilities at Washington, Tyne & Wear and Rotherham; a new composite centre in Bristol; a new facility in Solihull will open next year; and we are re-developing our Derby campus.

This submission covers our interest in autonomy across marine and aerospace applications.

Marine
Transport by water is the most energy-efficient means of moving cargo, equipment and people. Ships and shipping have a long history in the use of control systems and other technologies, including autopilots, dynamic positioning systems, automation and control, satellite communications and remotely operated subsea vehicles. The marine sector drives growth in the economy by enabling efficient transport. Whilst the recent reduction in oil prices has depressed the offshore oil and gas market, there has been increased activity in other areas of the marine industry.

Rolls-Royce is at the forefront of a drive towards introducing autonomous vessels within the marine sector, both in the UK and other countries. The promotion of autonomous ships for commercial operation was initiated only about two years ago when Rolls-Royce began to advocate the concept. In the past six months, practically all major marine technology suppliers have included remote operation and autonomy in their strategy (this has been made public through white papers etc.). The world’s first autonomous ship ecosystems/forums have been established in Finland and Norway in September of this year, and the first test areas for autonomous operations have been established.

The parallel development of autonomous road vehicles, aircraft and marine vessels could result in advantageous synergies where there is overlap. Situational awareness (knowledge of the world around) is an area which has seen rapid development in the automotive sector which is benefiting the marine application.

1. What are the potential applications for autonomous vehicles?

Marine
There is potentially a wide range of applications of autonomous marine vessels, e.g. surface vessels, in particular, present a great potential for the autonomy across almost the complete spectrum of activities. Existing research and development has been centred on small research and monitoring vessels, for example for testing water quality. The vast majority of the current vessels are small (no larger than 20 metres in length), are generally deployed from another, larger, manned vessel, and have a limited range of operation.

For the greatest return, the future trend should be towards commercial operation of much larger vessel types beginning with vessels that operate in a local area such as a port, for example, autonomous tug boats or launches. Further progression is likely to include larger vessels within a single flag-state, for instance ferries, local cargo and container vessels, dredgers and anchor handlers. Ultimately, the aim would be to encompass the vast majority of new-build vessels including bulkers (i.e. ships carrying bulk cargo such as ore or coal), container carriers, tankers, roll-on-roll-off ferries, offshore supply vessels, yachts and super-yachts.

Finally, there may be applications which are made possible or economic by the use of autonomous vessels which have not been viable before and represent disruptive technology, for example, ‘swarms’ of vessels used for survey or coastal policing.

**Aerospace**

There is a range of autonomous aerospace vehicle applications including Micro-UAVs (Unmanned Aerial Vehicles), to hand-held/launched ‘drones’, to small vehicle launched systems, and on to larger vehicles that require more significant infrastructure to operate. Rolls-Royce is currently only likely to provide propulsion and power systems for these larger vehicles and is involved in power and related systems on board larger (UAVs) that have a take-off weight in excess of 4 tonnes. Such UAVs have a range of military applications such as surveillance and reconnaissance (ranging from tactical UAVs, such as ‘Watchkeeper’ to high altitude long endurance UAVs such as Global Hawk), and the smaller of these applications have increasing appeal in the civil/security arena such as for road policing and border patrol for which long endurance operation is a distinct advantage.

Commercial applications of UAVs that exploit this advantage and will likely see further growth include pipe-line and power-line inspection for the oil/gas and electricity distribution, respectively. These applications fall under the ‘dull’ category of UAV suited tasks but further applications will facilitate tasks under the other oft cited categories of ‘dirty’ and ‘dangerous’, where human operation is best avoided. Emergency response in remote areas is one example where a UAV could be deployed to provide immediate assistance (e.g. search-and-rescue); to mitigate a crisis unfolding (e.g. fire-fighting); or to provide subsequent disaster relief (e.g. the delivery of humanitarian supplies). Future applications of UAVs could involve the transportation of significant payloads, both civilian and military, such as long distance air freight.

2. What are the potential user benefits and disadvantages from the deployment of autonomous vehicles?
**Increased safety.** A large proportion of accidents at sea are attributable to human-error, e.g. non-rational behaviour; varying degrees of knowledge, competence and experience; different perceptions to safety and risk; limitations in human data processing capacity; skill degradation (e.g. automation and controls skills are more important in the future than mechanics); misinterpretation of data; unpredictability; vessel behaviour based on captain’s personal characteristics; limited communication and logging of observations and decisions; fatigue and boredom. Therefore, by increasing automation and removing, or distancing, the human, it will be possible to reduce the number of accidents. At the same time, removing crew from vessels also means that fewer people will be present if an accident were to occur – taking people out of harm’s way.

**Reduced crew costs.** Perhaps the most obvious benefit for vessels owners and operators is the reduction of costs associated with crewing vessels. The cost of crew is, in many cases, the highest per-voyage overhead facing a vessel operator. It is becoming increasingly difficult to recruit the younger generation to life at sea – months away from home, limited access to social media and possible hardships. This has contributed to the demand for trained and skilful crews outstripping the supply, resulting in rising costs and a shortage of competent officers and engineers. Autonomous operation would enable land-based operators and engineers to oversee the operations of a number of vessels and thereby increase the desirability to a new generation, and reduce the numbers required.

**Reduced capital cost for vessels.** Removing the crew from a vessel allows the vessel design to be simplified. All of the life-support functions can be removed, including accommodation, air-conditioning, heating, lifeboats, water, food, lighting and recreation facilities. This will lead to smaller vessels for the same load-carrying capacity, with much less equipment required on board.

**Increased efficiency of ships.** With the reduced size of the vessel, the efficiency for a given pay-load will be increased, since the energy required to move a vessel through the water is directly related to the dimensions. The design of the whole vessel can be optimised for efficient running. For example, the accommodation block on a vessel incurs a significant wind drag as the vessel moves along. With no crew and no accommodation block, the vessel could be designed to be more aerodynamically efficient. With no life-support systems, energy usage for air-conditioning, heating and lighting, among others, will not be required, reducing the energy efficiency further.

**Reduced emissions.** With increased efficiency of the vessel in terms of aerodynamics, deadweight and operational dead-time, the amount of fuel used in the transport of goods and passengers will be reduced, leading not only to savings in cost, but also reductions in emissions of greenhouses gases such as carbon dioxide, as well as other pollutants such as sulphates and nitrates.

**Increased efficiency of transport operations.** Increasing the level of autonomy of the vessel is not limited to navigation. It is also possible, by digitally connecting the complete transport operation, to optimise loading, unloading, to integrate the movements and dockings of the vessel to its intended cargo and ultimately to optimise the complete logistics chain. The same technologies which will act as enablers for autonomous operation
will allow the maintenance of the vessels and its equipment to be optimised around its work. Leading to further efficiencies and reduced down-time.

**Technology spin-offs.** The development of technology required for full autonomy will have certain spin-off advantages which will increase the short-to-medium term benefits. For example, advances in situational awareness (i.e. detection and identification of other vessels, objects or obstructions around the autonomous vessel) required for computer control of a vessel will be used to improve the safety of manned-vessels by giving the captain, helmsman or pilot enhanced awareness. A further example is the automation of equipment on-board, including diagnostics of faults and self-repair, which will be required for autonomous operation, will be available for improved reliability on manned-vessels. Countries that participate in these developments by providing facilities such as digital ecosystems or test areas for autonomous vessels, will be able to reap the greatest rewards, including creation of high-tech jobs.

**Potential disadvantages**
There are some disadvantages associated with autonomous vessels. Some are generally well-known risks: automation of manoeuvres and data communication via satellite including cybersecurity. For some risks, there is limited current knowledge, for example interaction between manned and unmanned ships, operations in harsh weather conditions and complex operating situations. There will also be risks that are currently unknown, some of which may have been identified in the automotive arena, but some which will be completely new.

One identified area to be addressed is that of cybersecurity, which represents a major risk as a single source of failure in unmanned shipping. It could cause several critical functions to fail to operate as intended. The level of autonomy impacts the type of cybersecurity arrangements required. Remote operation from a shore control centre typically requires the ship and the centre to be connected in real-time, whereas autonomy lets the vessel operate without active control from shore.

**Aerospace**
The proliferation of small UAV suppliers is evidence of the numerous benefits and significant market access made available by their deployment and many of these benefits will apply to larger UAVs. The removal of the operator should result in the reduction in the scope for human error. As the extent of UAV on-board autonomy increases then lifecycle cost reductions will be realised from reduced operator presence and skill-level, and lighter, simplified UAV design without the need to accommodate the human operator. Furthermore, increasing autonomy will lend itself to 24/7 operation of UAVs.

Many factors will influence the more wide-spread use of UAVs such as cost, system reliability, robust control of system (e.g. reliable sense-and-avoid, ability to fly in cluttered environments, appropriate response to unexpected events); ability to fly with loss of GPS; emergency ‘get home’/land ability. Most of these are being tackled to an extent by the larger more sophisticated systems (including military), and a lot of this would need to translate into the smaller systems, since they face the same issues.
A significant barrier to more wide-scale adoption of UAVs is a dearth of risk assessment approaches, design standards and means of validation/verification that are specifically tailored to assuring autonomy related technologies. This barrier results in a reluctance to trust in and accept broader UAV deployment by customers, operators and certification bodies.

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

**Marine**
There are currently about 50,000 vessels in the international merchant trade, with a total crew of 1.2 million seafarers. This worldwide merchant fleet generates approximately £400bn in freight charges per year. The market value for autonomous vessels can be calculated from these based on potential reductions in capital costs, manning costs and fuel costs. It is estimated that capital costs and manning costs are, on average, approximately 25% each of total running costs, and that fuel costs are approximately 15% of total running costs. Studies into the design of unmanned vessels have estimated that the capital spend on vessels could be reduced by around 20%, whilst a similar saving would be possible on the fuel costs. Finally, at least two-thirds reduction in spending on manning could be achieved by removing crew from ships and utilising experts in onshore control centres. Combining these figures, the total savings across the industry would be around 20% of the total, or £80bn per annum. A significant proportion of these potential savings should be available for exploitation in the provision of the vessels, equipment and services which provide the capabilities of autonomous operation.

Within the UK, opportunities exist in a number of areas, including research and development (R&D), manufacture and operations. With its long maritime history, seafaring tradition and number of institutions involved in maritime research, the UK is in a strong position to be at the forefront of autonomous R&D. Whilst shipbuilding is no longer a major industry within the UK, there is potential to supply high-tech solutions and intellectual property for use on future vessels. Remote and autonomous operation makes it possible to control vessels of any flag state from the UK. This has the potential to permit vessel management, fleet management and marine operations in the UK. However, there is also a threat that if other countries are able to provide the expertise they will be preferred to the UK. Those nations that provide early support, education and infrastructure are likely to succeed.

There is a huge potential for the use of autonomous marine vessels to revolutionise the marine and shipping industries. Some of the key benefits include:

- Increased safety by removing human errors and having fewer people at sea.
- Reduced cost of shipping by reducing manning costs, capital costs and increasing fuel efficiency.
- Fewer emissions since unmanned ships can be smaller and more efficient.
- Optimisation of fleets and cargo in a digitally connected operation.
- Creation of high-tech jobs in countries that take a lead in providing digital ecosystems and autonomous test areas.
The UK and Rolls-Royce are currently in the vanguard of efforts to make this come about, but other players are moving quickly. The UK has the potential to become a major player in the further development of autonomous vessels and could reap major benefits from early adoption, with a huge potential market. Action from government and other UK institutions could greatly improve the effectiveness of UK development in order to harvest the greatest benefits. The current inquiry represents a welcome start to this process.

**Aerospace**

Applications at the smaller end of the UAV market are likely to move beyond the military, initially into the security sector and then into the civilian sector; indeed the largest markets will most likely be civilian applications. Typical applications could be:

**Security**
- Border patrol
- Anti-smuggling (goods and people)

**Day to day utility**
- Motorway patrol / Road traffic accident
- Oil / gas pipeline surveillance
- Powerline surveillance / fault finding

**Emergency utility**
- Oil depot fire
- Mountain rescue
- Coastal patrol / rescue
- Oil / chemical spillage at sea
- Nuclear powerstation emergencies
- Floods
- Adverse weather / heavy snow

Larger UAVs are currently the domain of the military, with a greater emphasis on being able to operate in potentially hostile environments (e.g. Predator, Reaper) and at high altitude, long range (e.g. Global Hawk). The emphasis is more on the utility of such systems and less so on cost. The level of sophistication is increased with a greater likelihood of bespoke sub-systems. The nature of propulsion and power for these platforms is for increasing requirements on power provision to the subsystems (e.g. surveillance sensors) with the associated challenge of managing the thermal environment within the platform. There may be some civil applications in areas such as earth observation where the intent would be for an observation platform/system that could be ‘on-station’ for very long periods of time. The future is quite likely to include combat UAVs in this class where the size is dictated by the ability to carry a payload over long distances.

UAV propulsion so far tends to be with existing engines (i.e. OTS – Off-The-Shelf), predominantly for cost reasons. However as the market demands more sophisticated systems then more bespoke solutions will become attractive, with technological advances such as hybridised power systems incorporating fuel cells, photovoltaics (i.e. solar cells) etc. With increasing autonomy, the requirement will grow beyond the provision of propulsion alone to intelligent on-board power management. The engine supplier’s scope of interest will thus broaden out to include for instance, demand monitoring and power distribution.
Increasingly lengthy unmanned operation will demand increasingly reliable on-board systems along with assurance of this reliability. Indeed, the emphasis will likely shift towards whole vehicle health management of integrated subsystems to include advanced condition monitoring; diagnostics/prognostics; and optimised maintenance and repair. In the future, market leaders are likely to be those who can best integrate systems, both internally within the platform and into the wider infrastructure. Consideration also needs to be given to how these systems are operated; in the civilian field there are a lot of likely interested parties who could not afford to develop a system on their own, but may be more interested to be part of a consortium for both developing and operating a system. So there could be a future significant market opportunity to provide a service to those interested parties.

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

**Marine**

Autonomous vessels already in use, or in demonstration, are using existing infrastructure in order to make progress. However, the full benefits of autonomous vessels will not be realised without changes to digital and physical infrastructure. There are significant technical challenges associated with ensuring safe and robust operation of autonomous vessels which could benefit from governmental influence or intervention.

On the physical side, ports may need to provide changes to their infrastructure in order for fully autonomous vessels to operate. For example, the berthing and loading/unloading of a vessel with no crew may require specific equipment at the quayside not available at present. Such a provision may also help to speed up the whole port operation.

The ultimate aim for autonomous vessels is for them to share sea-space with manned vessels. There may, however, be a requirement in the near-term to separate autonomous and manned vessels in congested areas like ports. In either case, whether autonomous vessels are separated or not, there will be a requirement for changes to sea traffic management to enable the full benefits to be realised. This is likely to include the provision of information concerning the movement and intentions of vessels being made available for the use of others in the area. There are initiatives being trialled in a number of European ports to digitalise sea traffic management, support for these initiatives within the UK is highly desirable.

In order to navigate a vessel, it is vital to have an accurate measurement of the actual position on that vessel. The primary method for position measurement uses global navigation satellite systems (GNSS) such as the global positioning system (GPS). In order to ensure security, it is necessary to have alternatives to GNSS which use alternative technologies. Currently there are few alternatives, but infrastructure could be envisaged to provide ‘digital lighthouses’ for example as a backup for GNSS. This could be a further possible area for support from government agencies.

**Naval applications**
The discussion to date has concentrated on commercial marine applications of autonomous vessels. There is a further potential benefit to the UK in the use of autonomous vessels in naval applications both surface and sub-surface. Development in autonomous airborne vehicles (drones) has been highly publicised and has proved to be extremely beneficial in reducing costs, increasing flexibility and reducing the dangers for pilots and military personnel. Currently, naval ‘drone’ technology is behind that of the aerial theatre, but developments in this domain are moving forward steadily.

The Royal Navy, like most European navies, is preparing to introduce small (<12m) unmanned vessels deployed from existing platforms to conduct specialist tasks such as mine countermeasures, surveillance and fleet protection. ‘Unmanned Warrior’, a large scale, multi-environment, military demonstration of unmanned technology has just completed off the west coast of Scotland. It combined industry, academia and defence partners, including the US Navy, to explore the feasibility of increasing the use of unmanned and autonomous systems in delivering maritime capability. Modern combatant designs, such as the Royal Navy’s planned Type 26 frigate, are increasingly including ‘mission bays’ to house and deploy such unmanned vessels. The US Navy is probably the most advanced in this area, they have commissioned a 40-metre proof-of-concept unmanned vessel, Sea Hunter, which is intended for anti-submarine and mine-hunting activities. In the longer term they believe that this type of vessel could replace manned anti-submarine warfare frigates, reducing running costs from $700,000/day to around $20,000/day and costing a fraction of the price of a larger manned platform.

Engagements with USN and RN unmanned programme teams indicate that large scale introduction of fully autonomous technology for combatant platforms is a long way off. It is envisaged that the rapid maturing of full autonomy in the commercial sector will pull through into naval new-build programmes in the form of semi-autonomy; decision support computer systems that analyse and contextualise platform data and present the operator with recommended options are very likely be introduced. This would further reduce specialist on-board manpower and improve warfighting capabilities. The only restraints to such an introduction is the slow pace of new build programmes as warships designed for service in the 2020s will be too early for the autonomy revolution and retrofits to warships currently in service are unlikely to prove cost effective since autonomy needs to be considered and implemented at concept design stage.

Clearly, autonomous technology could dramatically improve the capabilities in the naval sector. The UK could be far more ambitious in utilising the advances in the commercial arena and ensure that the requirements for new warships are future-proofed, allowing for the introduction of semi-autonomy as it matures through the next few years.

**Aerospace**

A more broad ranging deployment of UAVs will likely require infrastructure changes, the specifics of which will depend on the particular applications. A digital infrastructure is required that facilitates safe air traffic integration with robust remote command, control and communications that are both fault-tolerant and secure. Meanwhile, physical infrastructure such as dedicated runways or launch pads and associated facilities will likely
be required to accommodate increasingly larger UAVs so as not to diminish the capacity of existing terminals for passenger and freight transport.

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

There are many challenges that will need to be overcome before the widespread use of autonomous systems is realised:

- How do we demonstrate sufficient system reliability and integrity at platform/operation level (e.g. may need to incrementally demonstrate ‘in the field’)
- How can we build the public’s trust in an autonomous system
- How can we make the system sufficiently flexible to allow growth / upgrade
- What technological developments are essential
- How can the ability to communicate with the system be maintained at all times
- What other infrastructure needs to be put in place
- How can we ensure the security of the system (e.g. so it cannot be hijacked or compromised by external sources)
- How can we get developments out into the field more easily

These challenges are largely common to all such systems, whether in the air, sea or land domain. The difference will be the level of evidence needed to prove the system; air applications will be safety critical which will need a much higher level of integrity than in the land or sea domain, but in principle all will need to demonstrate an appropriate level of integrity for acceptance. Continued UK government support is pivotal to achieving the broader exploitation of UAVs such as state funding for technological development in low maturity areas and the engagement of public agencies such as the Civil Aviation Authority.

**Marine**

Autonomous shipping represents major challenges to the current regulatory framework. Autonomy means that there is a more pronounced major risk area of connectivity and cyber security on top of powering, propelling, steering and controlling a ship. Also, the importance of software development, validation, system reliability and functionality is increased. The legal liability and responsibility of system providers will increase with the introduction of more autonomous applications.

Much of the legislation on operation of marine vessels in the UK is based on the conventions issued by the International Maritime Organisation (IMO). For example, the International Convention for Safety of Life at Sea (SOLAS), the International Convention on Standards of Training, Certification and Watch-keeping for Seafarers (STCW) and the Convention on the International Regulations for Preventing Collisions at Sea (COLREG). The wording of these conventions, and of other legal instruments, relies heavily on the assumption that there is a crew on board, including a master. This leads to an ambiguous situation when considering autonomous vessels. Recently, some nations have given input to IMO 2018-2023 strategy to include aspects of unmanned shipping.

It is recognised that the international conventions would be unlikely to be altered in the short term. International rules evolve slowly due to the complex approval process by
member states and the required minimum country adoption rate before new rules or amendments take place. Vessels operating within a single country can be exempted from international rules by the approval of a national authority. UK legislation could, and should, be used to clarify the situation within UK coastal waters in order to accelerate development of autonomous vessels here. Other flag states are already addressing the issue of local legislation in order to try to foster further development.

Unmanned shipping represents a quantum leap in shipping as we know it. Therefore, a mere regulatory compliance is not a sufficient approach. It is recommended that the marine industry applies best practices from the aviation industry by implementing holistic safety management.

Insurance, liability and classification rules are also areas in which the introduction of autonomy represents largely uncharted waters. Recently, the trend has been towards probabilistic and goal-based rules that can be applied to novel applications. While this provides a possible upgrade path, it is yet to find credence with insurance companies.

**Aerospace**

A comprehensive review of both the national and global position on insurance, regulation and legislation involving all relevant stakeholders is essential to establishing a shared understanding of the difficulties and barriers to a more broad ranging deployment of UAVs. Such a review is key to identifying proposed revisions and operational restrictions/limitations, and encouraging standards development, to facilitate more ambitious applications of UAVs than exist today. In the first instance, principles are required for the operation of increasingly larger UAVs and increasingly sophisticated roles. A position should then be developed on their safe integration to the airspace as it exists today in and amongst conventional air traffic.

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