Project AUTONOMAD: The design of an unmanned coast guard vessel integrating the use of drones for emission regulation enforcement and territorial water protection in the Mediterranean

M. Cheliotis, E. Trivyza, G. Koufos, I. Papadimitriou & J. Evans
University of Strathclyde, Glasgow, UK

ABSTRACT: Project AUTONOMAD examines the design of an unmanned trimaran vessel for unmanned application, integrating the deployment, recovery and storage of various Unmanned Aerial Vehicles (UAVs) and Unmanned Surface Vehicles (USVs). It is tailor made for the needs of EU Coastguards in order to provide a platform for emission regulation enforcement, maritime monitoring and surveillance in the Mediterranean. This project includes the design of the unmanned vessel, the selection of its payload and the integration of the unmanned technologies in order to create a robust, reliable and safe engineering system. The feasibility of such a vessel is then assessed in terms of reliability and overall benefit.

KEYWORDS: unmanned; emissions; surveillance; integration; safety;

1 INTRODUCTION

1.1 *General*

Project AUTONOMAD is the concept design of an unmanned trimaran coastguard vessel. The vessel's main missions include territorial water protection and the enforcement of IMO's emissions regulations. The conceptualized trimaran is intended to assist on the enforcement of the emissions regulations in the Emission Control Areas (ECA), Sulphur Emission Control Areas (SECA) and Nitrogen Emission Control Areas (NECA) zones with respect to SOx and NOx concentrations. Through the use of specially selected drones mounted with appropriate sensors, Project AUTONOMAD will offer accurate and real-time emissions measurements. That way, the compliance with the existing IMO rules will be assessed. Additionally, through the use UVSs, UAVs and other equipment, the designed vessel will assist in the maritime boarder surveillance and protection. The unmanned nature of Project AUTONOMAD offers a vessel that can undertake high risk operations while creating a safe operating framework for the human operators.

1.2 *Operating area*

As mentioned, Project AUTONOMAD is tailored made for the needs of EU coastguards. The key reasons that led to the selection of EU are two. Firstly, there is lack of infrastructure for wide area coverage with the use of multiple sensors and integrated technologies in the EU. This results in lacking ability to identify small targets in coastal regions and in unorganised communication between various stakeholders and systems (Council of the European Union, 2008). Secondly, there is a lack of standardised procedures for the enforcement and auditing of ships' emissions in the EU. Additionally, many stakeholders of the maritime trade industry support the use of sensor-carrying UAVs for the emissions verification (Trident Alliance, 2015). As a result, Project AUTONOMAD was conceptualized to cater for the above issues with the aim of integrating different technologies and creating a robust and reliable engineering system.

1.3 *Mission*

The main mission of Project AUTONOMAD is the creation of a vessel that is driven by its functionality. In detail, the functionality of our platform is met through the creation of a design that can undertake different missions, carry out high risk operations, offer a large operational range and provide a reduced operational cost. Additional key factors include the use of reliable state-of-the-art technology, offering high accuracy operations and enhanced operability.

The realisation of the above is met through the following:

- The selection and utilisation of UAVs mounted with sensors to monitor in real-time the emis-

sions of a ship to enforce the current emissions regulations.
- The selection and utilisation of a combination of UAVs and USVs to perform patrolling and surveillance tasks.
- The design of an unmanned vessel assisting in the operation of the above assets.

2 DESIGN

2.1 *Hullform selection*

During the preliminary phase of the design different types of hull-forms were examined in order to determine the optimum choice with respect to the operational requirements. The decision between monohulls and multihulls depends on if the ship is volume or mass limited. If the ship is mass limited, monohull is the best choice. However, for volume limited vessels and especially when larger deck space is required multihulls are more suitable (Watson, 2002). Under the scope of this study the monohulls, trimarans and Small Waterplane Area Twin Hulls (SWATH) were examined and compared to identify the most suitable option for our design. These types of hulls were inspected in terms of specific features vital to perform the required operations. The following were the most significant factors affecting the final choice:

- The available deck area needed to be as large as possible to launch, recover and store the UVs employed for the missions.
- The resistance of the vessel had to be as low as possible for the operating speed to minimise the required fuel and costs to cover the maximum operational area.
- The seakeeping behaviour of the vessel needed to provide a large operational window. Thus, minimised motions were identified to be vital for undertaking operations under most sea-states.
- The structural reliability of the selected hullform had to be high, reducing the downtime due to structural repairs.
- Other factors such as the stability of the vessel, initial and life cycle costs and complexity of the construction and design were also accounted for, as secondary criteria.

Many factors were involved in the selection of the final hullform. An important factor was the available deck area. A large deck space is required to allow for the successful launch, recovery and handling of the selected UAVs and USVs. On that criterion, trimarans demonstrated the best performance, in combination with the overall complexity of the design. Good stability and low resistance were also paramount to the selected design. Through these factors, large operability and increased operational area are achieved (Coppola & Mandarino, 2001). For these criteria, trimarans demonstrated the best performance due to their inherent design characteristics (Betorello, et al., 2001). Lastly, the initial and lifecycle costs and the number of available shipyards were examined. On these criteria, monohulls and trimarans showed similar performance.

Due to the exceptionally high initial and lifecycle costs and in combination with the increased complexity of the design, SWATHs were not considered any longer. Additionally, the reduced structural reliability of the SWATHs due to the risk of structural failure of the struts influenced the decision to disregard SWATHs. On the contrary, due to the reduced resistance, increased stability and innovative nature, the trimaran hullform was selected.

A joined UK and US study examined the feasibility of trimaran as future combatants in navies and coastguards. The study concluded to the following advantages of a trimaran when compared to an equivalent monohull (Short, 2000). These are as follows:

- The reduction of the hull resistance can lead up to a 20% decrease of the total resistance.
- The stability advantages offered by the outriggers allows for heavy equipment such as large radars to be fitted more easily than in monohulls.
- The additional stability benefits in the area of growth margin and allows for easier and less expensive upgrades during the life cycle of the vessel.
- Trimarans are the optimal solution for fast vessels, with a large over-deck area for multiple operations and maximised operability (MARIN, 2000).

2.2 *Characteristics determination*

Due to the novel nature of the trimaran, the dimensions and characteristics of Project AUTONOMAD were determined by using two databases. The first database was concentrated on the existing coastguard patrol fleet of EU countries (mostly monohulls). Through that, the capabilities of the existing vessels were identified. Thus, the proposed design should be able to achieve and overcome the operational characteristics of the available current patrol crafts. The second database included trimarans of a great range of displacements and vessel types. This assisted on identifying design ratios that could be used for establishing the initial dimensions of our platform.

Based on the aforementioned databases, the main hulls and the two outriggers were addressed separately. As a result, the Maxsurf Modeler software was used for the parametric manipulation of the hulls. Once the underwater part of the trimaran was finalised the model was imported to Rhinoceros 5 to introduce the above water part of the vessel.

For the powering prediction, the Maxsurf Resistance software was used to have a first approximation of the drag. In order to estimate the resistance of trimarans the Slender Body Method (SBM) was employed, which accounts for the interaction of the multi-hulls. This is of great significance since any other method available for the resistance prediction would not provide accurate results. In simple terms, the SBM calculates the ship's energy dissipated in generating the wave pattern of the free surface. Thus, it calculates the wave making resistance and accounts for the interaction of the different hulls and their effect on the wave making resistance (Hafez & El-Kot, 2012).

2.3 *Optimisation and weights estimation*

To select the optimum side-hull configuration in terms of the minimum required Effective Horse Power (EHP) and the most promising ship responses, the Proteus software which is part of Paramarine was used. Proteus is a frequency domain seakeeping module based on a 2D Rankine Source solution of the hydrodynamic problem. The code works by solving the reaction/diffraction coefficients for a number of 2D solutions (transverse sections of the hull) and integrates the coefficients longitudinally to provide total force coefficients. Since the operating area is the Mediterranean, appropriate spectral wave data were used.

Once the side hull configuration was selected, the initial weights estimation was undertaken in order to examine if the geometric displacement of the vessel matched the weight calculated displacement.

The LS comprised of the structural weight, machinery weight, outfit weight and a margin. Due to lack of data, the structural density of RV Triton trimaran project, which was developed as part of a MoD research, was used for the estimation (Naval Surface Warfare Center, 2011). The machinery weight involved the weight of the engines required for the propulsion as given by the manufacturer, which at this stage was taken as the maximum weight given for engines capable of the required power output. Also, the remainder machinery is considered, which is related with propulsion, auxiliaries, etc. and the weight of the machinery is given as (Parsons, 2003). The outfit weight was estimated as a percentage (30%) of the structural weight of the trimaran. Lastly, the margin was taken as 2% of the lightship. An additional 0.5% of the lightship (growth margin) was used per annum of intended life (Naval Surface Warfare Center, 2011).

The deadweight comprised of several weight groups, especially for Project AUTONOMAD its payload is the UAVs and USVs carried for its missions. Moreover, since the vessel is unmanned the weights of crew, baggage and provisions were not considered. The payload weight was calculated based on the number of UAVs and USVs carried as well as their weight as provided by their manufacturers. The fuel oil weight was estimated based on the vessels endurance, Break Horse Power (BHP) at the cruise speed and the SFOC as given by the manufacturer. The endurance of the vessel was selected to be 3000nm, which made it far more competitive than the existing Offshore Patrol Vessel (OPV) fleet of the EU Mediterranean countries, in terms of autonomy. The lube oil weight was calculated on a similar manner to the fuel oil. Lastly, the payload refuelling weight was calculated based on the number of refuelling for each of the USVs and UAVs, based on their endurance, required fuel and operating assumptions.

2.4 *Final Design*

By following the described process, a 601.3 tones trimaran was designed. The vessel is 55.5m long at the waterline and 18.1m wide. It has block coefficient of 0.467, which was calculated based on Lloyds Rules for Trimarans (Lloyd's Register, 2016). The following figure shows the resulting midship section.

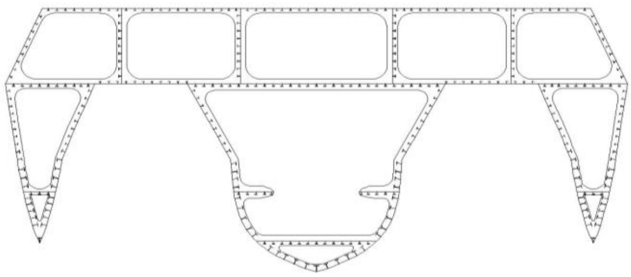

Figure 1. Midship section

The following figure shows the resulting trimaran along with its equipment and payload.

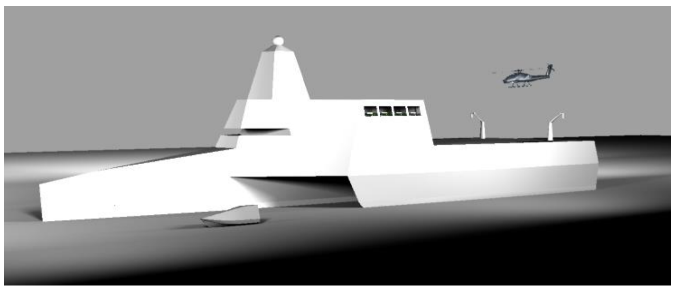

Figure 2. Trimaran with UAV and USV on mission

3 ENGINEERING

3.1 *Unmanned vehicle payload*

Identifying and selecting the UVs that would be used for missions of the designed trimaran was extremely important.

For the emissions regulation enforcement, it was decided to use “Project Sense” from Explicit. Explicit is a technology company, based in Denmark, specialising in systems for sensor data acquisition. Project Sense is a cost efficient and reliable platform aimed at emissions monitoring. It combines drone technology and information from the automatic identification system of a ship, during cruising, to analyse sample plumes to detect non-compliant behaviour in term of emissions regulations. Project Sense is specifically designed to seek, sample and deliver sensory data in a situation where the traditional manned inspection is challenging. The Project Sense drone is very compact, with a length of 1.2m and a wing span of 1.9m (Explicit, 2014).

Part of the patrolling and surveillance mission of Project AUTONOMAD will be carried out using unmanned surface vehicles. From the available USV found in the literature, it was decided to use Hydra. Hydra is a 4m long high speed rigid-hulled inflatable boat. Hydra is equipped with a broadband frequency-modulated continuous wave radar, forward-facing sonar, low light and Infra-Red (IR) video camera (5G International, 2015).

For the patrolling and the surveillance missions of our platform it was decided to use a Vertical Take-Off and Landing (VTOL) UAVs. After research, the Tanan UAV was selected. It is a UAV developed by Airbus Defence and Space to serve as a multi-sensor concept. It is equipped with electro-optical and IR cameras, maritime radar and direction finder. Tanan is 5.2m long, 2.1m tall and has a rotor diameter of 6.3m (Airbus Defence and Space, 2015).

3.2 *Power plant configuration*

The selection of the ship’s power plant and its configuration were essential steps in the project. The selection of the power plant was based using Multi Criteria Analysis (MCA) techniques. These require the use of judgement to examine different options based on specific criteria. They are used to identify the most preferable option within a group of available outcomes. As main propulsors, 4-Stroke (4S) engines, Diesel-Electrics (DE) and gas turbines were considered. These options were assessed in terms of emissions, reliability, vessel applicability, noise and vibration and optimal load operation. Consequently, the DE was selected, primarily due to fuel saving, space flexibility and safety.

The following figure shows the power plant configuration used in Project AUTONOMAD. As it can be observed, two 4S engines (Wärtsilä 16V26) are connected to the main switchboard. From there, an electric motor (AC Synchronous) drives two fixed pitch propellers through a single-input-double-output reduction gearbox.

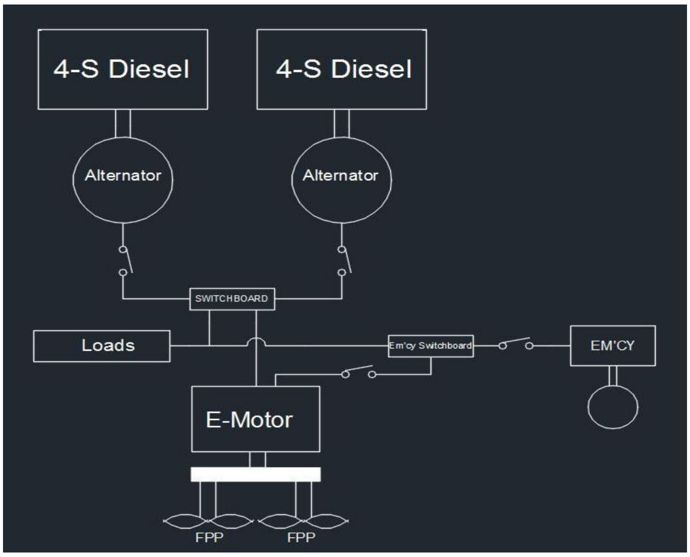

Figure 3. Power plant configuration.

3.3 *Electric loads*

Prior to the selection of the specific diesel generators, emergency generators and electric motors, the exact determination of the electric load was necessary. Consequently, an Electric Load Analysis (ELA) was performed. The first step for the ELA was to compile and electric load list, detailing all the electric consumers onboard the vessel. Then, rated powers were allocated to each of the detailed loads. Lastly, power factors were assigned and the power demand of each load was found (Department of Navy, 2012). In detail, machinery room, ventilation, positioning, lighting and navigation loads were considered:

3.4 *Operating profiles*

For a more accurate electric power demand calculation five different operating profiles (conditions) were considered. Each operating condition uses different types and numbers of machinery and equipment according to the profile's needs. The selection of the units and their numbers in operation was made using engineering judgment. The operating conditions are normal speed, maximum speed, manoeuvring, stand-by and emergency operation.

In normal operation, the vessel travels at 19 knots (cruising speed). Normal operation would be required during routine patrolling and surveillance and in conditions that do not require enhanced speed. The two main diesel generators are in operation, producing electricity, which is then distributed to various consumers via the main switchboard. Most of the sea water, fresh water, ballast, MDO transfer, MDO purifying, lubrication oil transfer, lubricating oil purifying and payload related pumps are operational. All the auxiliary units, which serve redundancy, are on stand-by.

During maximum speed operation, the vessel requires very high power demand to achieve 24 knots (maximum speed). Such operating conditions would occur in cases of surveillance and patrol where the fast intervention of our trimaran is paramount. Similar power requirements could occur in many different situations. For example, during the emergency recovery of the USVs in case, they lose power while on a mission. To serve this operational need, almost all of the engineering systems are used to provide for sufficient cooling, lubrication and fuel supply of the generating engines.

During manoeuvring operations, the vessel travels at very slow speeds, up to 2 knots. The defining characteristic of this operational profile is the use of the ship's bow thruster. Such operating conditions would occur either when the ship is attempting to berth, or more importantly when the vessel is recovering its deployed payload.

The speed limitation is imposed because at speeds greater than 2 knots, the flow, inside the bow thruster's tunnel and around the bow thruster, is very poor. That way the effectiveness and efficiency of the thruster are decreased, while risking causing damage to the thruster itself (Murdoch, Dand, & Clarke, 2012).

In the stand-by mode of operation, the vessel is assumed to be stationary in port. Stand-by mode would be required in many different situations. An example of such a case would be when the vessel has not been assigned any missions. Moreover, maintenance, refuelling and restocking needs of the vessel could also require the stand-by mode of operation. Due to the operating area of our trimaran, there is a possibility for a lack of an onshore electric power connection in the ports our vessel could call. For that reason, the electrical power demand of the ship for that mode was obtained taking into account that the diesel generators of the vessel are in operation.

The emergency operation of the vessel indicates the presence of a mechanical or electrical failure. Because the vessel is unmanned, she must comply with high redundancy standards to ensure a safe operation. The emergency system is completely separated from the other systems of the vessel. It consists of an emergency diesel generator, an emergency switchboard, an emergency fuel tank and an emergency fuel pump. All this equipment is allocated in a separate compartment of the vessel. The system is configured to automatically assume load upon the loss of normal ship-service power (Clelland, 2015). According to DNV-GL, in the case of emergency, the ship is required to produce a minimum power in order to return safely to the nearest port. The speed of the vessel does not need to exceed 6 knots, and the vessel must be able to travel with winds up to 8 Beaufort (DNV-GL, 2015). For that reason, the emergency generator produces much lower power than the main diesel generators. In the emergency mode, most of the electrical consumers are off.

3.5 *Systems and networks*

The main networks and systems, which are vital for the ship's operability and safety, were designed. These are namely, the fuel oil networks, the lubricating oil network, the ballast system, the cooling network as well as the firefighting system.

Regarding the fuel oil transfer and filling networks, the vessel requires three different types of fuel in order to supply the main diesel generators, the two Hydra USVs, and the Tanan UAV. The diesel generators are using marine diesel oil for their combustion process, both USVs petrol fuel, whereas Tanan uses diesel oil. It is obvious that different service tanks are required onboard to store the various types of fuel.

The Fuel Oil (FO) feeding system contains five different service tanks and five feeding pumps in total, to feed the various USVs, UAVs, and the main diesel generators.

One of the most important systems that had to be integrated into our vessel was the Firefighting System (FFS). Its importance is further increased due to the unmanned nature of our design. The biggest challenge is the fact that conventional systems that rely on the physical intervention of human operators (use of portable fire extinguishers) are not applicable for our platform. The FFS system is employed to protect the enclosed spaces of our vessel, including the payload space, the engine rooms, pump rooms as well as the superstructure. After consideration and consultation with academic experts, it was decided to use a CO_2 flooding system. In, details the advantages of using CO_2 as a firefighting medium are (Marine Insight, 2012):

- It is a proven and effective way of extinguishing fires, with a wide range of application in the engine rooms of merchant and naval ships.
- Carbon dioxide settles down and starves the fire by displacing oxygen.
- It is easy to liquefy CO2 and store it in a cylinder.
- It has a high expansion rate once released.
- No clean-up is required after CO2 discharge.
- It is a non-corrosive substance and does not deteriorate with age.

Nonetheless, one main disadvantage of carbon dioxide is that it is highly toxic and asphyxiating to human personnel. However, since no humans will be onboard during the normal operations of the vessel, this drawback is no significant risk

3.6 *Vessel and payload control*

One of Project AUTONOMAD's novelty features is its unmanned nature. Hence, one of the most fundamental parts that must be examined is how this unmanned vessel will be controlled. In particular, this section will highlight the key systems and the functions of the Shore Control Centre (SCC), as well as communication links between the centre and the unmanned vehicles.

The SCC will control both the host vessel as well as its payload (UVs), via a Tactical Control System (TCS) software package. This software has been developed for the control of unmanned vehicles and has been already used on military UVs (University of Maryland, 2007). The TCS software delivers a graphical user interface for onshore operators along with full control of data dissemination to the command, control, communications, computers, and intelligence architecture (C4I). The main capabilities of the system are mission planning, mission control and monitoring, as well as payload data processing. The main communicational link between the SCC and the UVs is via the Tactical Common Data Link (TCDL), while a secondary Ultra-High Frequency/Very-High Frequency (UHF/VHF) data link is utilized to provide a backup for command and control. Through the TCS, the operators receive real-time imaging and electro-optic and infrared feed from the UVs as well.

The TCS is divided between two operators: the Host Vessel Operator (HVO) and Mission Payload Operator (MPO). The HVO undertakes the monitoring of host vessel status as well as the control of launch and recovery systems (LARS). The HVO is also responsible for conducting host vessel operations including mission planning and data recovery. The MPO has the primary tasks of monitoring the health, status and operation of the payload UVs, evaluating payload data and performing real-time operation of the payload UVs.

The main connecting links between the SCC and the UVs is the Vehicle Management System (VMS), which is the core system to manage all the critical operations of the UVs. The vehicle management system is integrated in each UV. The VMS is composed of dual-redundant Vehicle Management Computers (VMC). Dual-redundant buses are utilized to support critical items and data timing constraints. The VMC is the controller for each bus. The VMC and buses operate in a master-slave configuration where only the master issues commands and the slave listens to ensure the master is operating correctly. The following figure demonstrates the control system for the trimaran. Similar systems are used to control the vessel's payload.

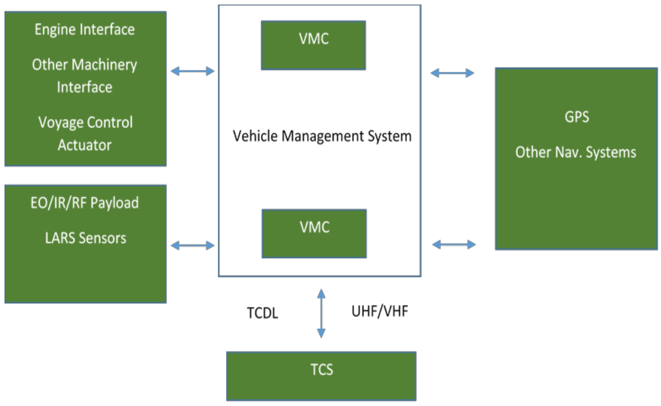

Figure 4. Trimaran VMS

4 SAFETY AND RISK ASSESSMENT

4.1 *Methodology*

The first part of the adopted methodology was the identification of the hazards (HAZID). The items that were considered include hazards to the safety of the vessel and operability of its systems. The items of the list were then subjected to further evaluations using various risk assessment tools. Additionally, HAZID allows for a qualitative evaluation of the identified items on the list (Lazakis, 2016). The identification of the hazards was based on the judgement of the engineering team. Moreover, it was based on the assumption that all the major components of the shipboard systems pose a hazard (equipment failures and errors). Lastly, external hazards (weather, collisions, hostile activity).

As soon as the HAZID was completed, the items on the list were evaluated using a risk assessment tool. Due to past experience, academic advice and industry wide appreciation, it was decided to the Dynamic Fault Tree Analysis (DFTA). The DFTA was performed by using the PTC Windchill programme, which is a dedicated reliability assessment software. Due to lack of operational data, the risk assessment was restricted in the use of a qualitative DFTA.

4.2 *Aims*

The main outcomes of the analysis were two. First, it was the creation of a visual model demonstrating the foreseeable paths to failures. The visual model can give an insight on the chain of causality and it can also facilitate additional analysis. Then, was it was to obtain cut-sets (CS), showing the shortest paths to the compromise of the ship's safety and operability. CSs were also used to identify the most critical hazards of our vessel. Based on the results obtained from the CS risk reduction and mitigation measures were proposed. CSs are used for the qualitative assessment of the system's fault tree structure. The main advantage of CS is the ability to understand the mechanism of a failure without having operational data available. They can also aid in the identification of weak links and critical components.

4.3 *Results*

One of the main outcomes of the DFTA was the determination of the cut-sets. The PTC software can evaluate all the cut-sets of the fault tree, which are spread over multiple orders. Nonetheless, it was decided to use only the first four CS from the smallest order. This decision was based on academic advice and examination of the resulting CSs. Based on those results it was concluded that the two generating engines of the ship are the most critical components. As a result inspections by onshore personnel during port visits are suggested. Moreover, the use of vibration monitoring to assess the performance and state of the engine is also recommended. Additionally, the second most critical component was the Tanan UAV. As a result, additional visual inspections during port and the use of cameras installed on the hangar and weather deck to supervise launch and landing are encouraged.

5 DISCUSSION

Project AUTONOMAD involved the integration of many challenging aspects. Starting from the novelty of an unmanned vessel, where no significant literature was available in order to create a well-established background. Even though diverse unmanned and automated technologies exist, there was no precedence in the marine sector. Thus, identifying and integrating the available state-of-the-art technologies was of paramount importance. The completion of a basic risk and reliability analysis was paramount to ensure that the safety of the platform was addressed. On another notice, the selected hullform while being the optimum to meet the project's objectives revealed many challenges regarding compartmentation and machinery layout.

REFERENCES

5G International, 2015. *Hydra.* [Online] Available at: http://www.5gmarine.com/hydra/ [Accessed 14 November 2015].

Airbus Defence and Space, 2015. *Unmanned Aircraft Systems.* [Online] Available at: http://militaryaircraft-airbusds.com/Aircraft/UAV/Tanan.aspx [Accessed 14 November 2015].

Betorello, C., Bruzzone, D., Cassella, P. & Zotti, I., 2001. *Trimaran model test results and comparison with different high speed craft.* Shanghai, Proceedings of the 8th International Symposium on Practical Design of Ships and Other Floating Strictures.

Clelland, D., 2015. Marine Power & Electrical Systems, Glasgow: University of Strathclyde.

Coppola, T. & Mandarino, M., 2001. *The design of trimaran ships: General reviews and practical structural analysis.* Shanghai, Proceedings of the 8th International Symposium on Practical Design of Ships and Other Floating Structures.

Council of the European Union, 2008. *Maritime Surveillance-Overview of ongoing activities,* Brussels: European Union.

Department of Navy, 2012. *Electric Power Load Analysis For Surface Ships,* Washington: Department of Navy.

DNV-GL, 2015. Propulsion, power generation and auxiliary systems Pt6Ch2, Høvik: DNV-GL.

Explicit, 2014. *Project Sense,* Lyngby: Explicit.

Hafez, K. & El-Kot, A., 2012. Comparative investigation of the stagger variation influence on the hydrodynamic interference of high speed trimaran. *Alexandria Engineerinng Journal,* Volume 51, pp. 153-169.

Lazakis, I., 2016. *Systems Availability and Maintenance,* Glasgow: University of Strathclyde.

Lloyd's Register, 2016. *Rules for the Classification of Trimarans,* London: Lloyd's Register.

MARIN, 2000. *Comparison of Comfort and Workability on board a Trimaran and a Monohull Yacht,* Amsterdam: Maritime Research Institute Netherlands.

Marine Insight, 2012. *12 Things You Must Do Before Operating Ship's CO2 Fire Extinguishing System.* [Online] Available at: http://www.marineinsight.com/guidelines/12-must-do-things-beforeoperating-co2-fire-extinguishing-system-for-engine-room-fire/

Murdoch, E., Dand, D. I. & Clarke, C. C., 2012. *A Master's Guide to Berthing.* 2nd ed. London: The Standard.

Naval Surface Warfare Center Carderock Division, 2010. Unmanned Sea Surface Vehicle (USSV) Motion Data and Refuelling Equipment Design, Virginia: Naval Surface Warfare Centre Carderock Division.

Parsons, M., 2003. Parametric Design. In: Ship Design and Construction. New York: Society of Naval Architects and Marine Engineers, pp. 11-3-11-50.

Short, R., 2000. *R.V. Triton-Project Outline, Aims and Objectives, the integrated Project.* Southampton: RINA, R.V. Triton: Trimaran Demonstrator Project.

Trident Alliance, 2015. Who We Are. [Online] Available at: http://www.tridentalliance.org/who-we-are/[Accessed 30 November 2015].

University of Maryland, 2007. Triton: Advanced Deployable Compact Rotorcraft, Maryland: University of Maryland. Watson, D., 2002. Practical Ship Design. Second ed. Oxfrord: Elsevier Science Ltd.