A Capability Based Approach for Warship Design

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***Abstract*— Traditional Naval Warship design is based on a rather sharp separation between two domains: the Platform and the Combat System. Naval engineers are primarily concerned with the Platform, with tight interaction with other disciplines such as mechanical and electrical engineers. On the other hand, Combat Systems engineers are more concerned with the technological component of the Warship, working in tight coordination with electronic, software or telecommunications engineers. The resulting system (the Warship) is often closer to a *Federation of Systems*, with more or less controlled interactions among each other, rather than to a truly *integrated system*. The focus of this paper is to present a novel approach to the design of a Warship that avoids the a-priori distinction between Platform and Combat System, but considers the Warship as a single, coherent whole. Thus, the approach shifts the focus on the level of the whole warship's capabilities, and its related measures of effectiveness and performance, rather than on its components and subsystems. The aim of such effort is to increase the mutual awareness of the problems specific of each of its components among the entire range of teams called to design, develop, produce, integrate, test and maintain a system as complex as a modern Warship.**

Keywords-capabilities; systems engineering; naval; ship design.

I. INTRODUCTION

Naval ships are increasingly large, complex and technologically advanced systems, suggesting a review of the traditional ship design procedure to better tackle with the interdependent ship aspects and to rationally identify the ship final configuration, able to meet operational requirements within technical an programmatic constraints.

Along the decades, interesting discussions and proposals about new ship design philosophy have been launched [1][2], mainly exemplified with applications in the naval ships' fields [3]. In particular, the Systems Engineering approach is recognized as a powerful guide to rationally and successfully develop complex systems [4][5][6].

In the perspective to capture and manage the interactions between the vessel (the ship meant as a platform) and the different installed systems on board (the so called "payload"), from multiple points of view and in a concurrent accomplishment, Systems Engineering appears to offer an effective support, based on a system thinking paradigm rather than on a reductionist and mechanistic view. In fact, it enables to overcome the traditional approach limitations and to focus, since the early design phase, on the naval ship functions rather than on the several singular components the ship is made of.

This radical change of mindset implies that ship performance is to be pursued and observed as an emergent property i.e., as arising from the collaborative functioning of different parts of a system, but not expressed by any of the individual items alone. Typical examples are ant colonies, a flock of birds, the bees hive and, of course, our brain. In other words, emergent properties manifest themselves as the result of various system components working together, not as a property of any individual component.

The term "emergent" is used within systems theory, biology, chemistry, ecology, science, philosophy. Since emergent properties are accessible and evident at higher levels of analysis, only examining individual parts of the system will prevent one from seeing them.

The necessity of a comprehensive ship performance prediction regarding the ship system as a whole, characterized by significant complexity, motivates the exploitation of "tools" like the "measurements of performance" and the "measurement of effectiveness", suggested by Systems Engineering.

As a starting point, ship capabilities need to be identified and discussed. In the perspective of what stated above, they may represent, in fact, the Warship emergent properties to pursue as design goals, and required to comply in turn with the customer expectations.

The paper is structured as follows:

- Section I: the present Introduction
- Section II: a description of the Capability approach
- Section III: a detailed description of the taxonomy of Capabilities
- Section IV: a preliminary analysis of Capability interdependencies
- Section V: the Conclusions

II. THE CAPABILITY BASED APPROACH

The INCOSE Systems Engineering Handbook [7] defines a Capability as "an expression of a system […] ability to achieve a specific objective under stated conditions". It is rather common in Warship specifications to find descriptions of the abilities of the "Combat System" to achieve specific objectives, such as "Command and Control", "Combat" or "Surveillance" [8][9]. Very few references can be found [10][11] to the basic abilities of the Warship itself, in its quality of "ship" before anything else, such as the ability to float on the surface of the sea, or the ability to remain stable in an upright position in order to allow any activities to be carried onboard.

Section III of this paper describes an innovative effort, to further deepen the topic and contribute to the relevant naval literature, aimed at the definition of the Warship Capabilities in order to provide a coherent framework for the categorization of the key performance requirements of the Warship. This is achieved by reducing the complexity of the Warship through a decomposition of the *problem* (the Capabilities that the Warship has to exhibit), rather than of the *solution* (the systems and subsystems that will be part of the Warship). Nevertheless in the following the Warship Capabilities are discussed in their details in order to start paving the link with the solution domain.

III. DEFINITION OF THE WARSHIP CAPABILITIES

A possible categorization of the capabilities related to a Warship should start with the obvious recognition that the Warship itself is a ship in its own right, and even before, that it is a platform floating on the sea, used by and interacting with human operators.

The basic Capabilities for any sea faring "platform" are shown in Figure 1 and can be recognized as:

- **Buoyancy**: the platform has to float on the waters, carrying its load
- **Stability**: it has to avoid capsizing
- **Structural Strength**: it has to avoid falling apart

Following the analysis, any such platform needs to be operated by humans, and will interact with them, with man made infrastructures, and with the environment, and so needs the following Capabilities:

- **Safety**: no humans, or their properties, or the environment, should be harmed
- **Security**: it should not be tampered with malicious intent

The next step is to consider the Capabilities that are necessary to make use of such platform as a "ship":

- **Power Generation**: either by oars, sails, or engine and propeller, the platform needs to sail
- **Controllability**: the operators need to control its heading and speed
- **Navigation**: the operators need to know where it is located on the earth surface, and where they intend it to sail

The type of ship we are interested in is a modern platform, with automated functions, and technology aiding the human operators in all their tasks, and this brings to the next required Capabilities:

- **Command and Control**: the computer based automation of all operations performed through the ship's equipment
- **Communications**: the means to exchange voice, data, and other types of information, among the on board persons, and with the outside world

Finally, we have to consider the ultimate Capabilities that make our ship a Warship, able to carry out its intended missions:

- **Surveillance**: the Capability to discover and monitor any potential threats
- **Combat**: the Capability to neutralize those threats

The following Figure 1 shows a representation of all the identified Warship Capabilities, which are described one by one in the next sections:

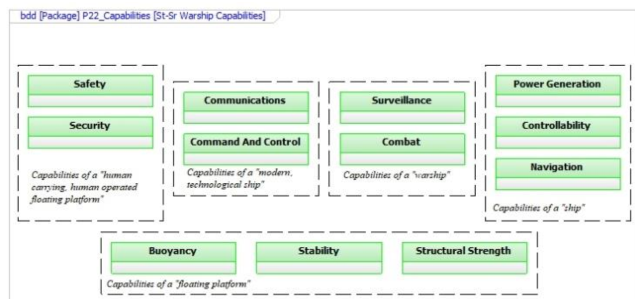

Figure 1. Warship Capabilities.

A. Buoyancy

Buoyancy is the Warship's Capability to float above the sea surface.

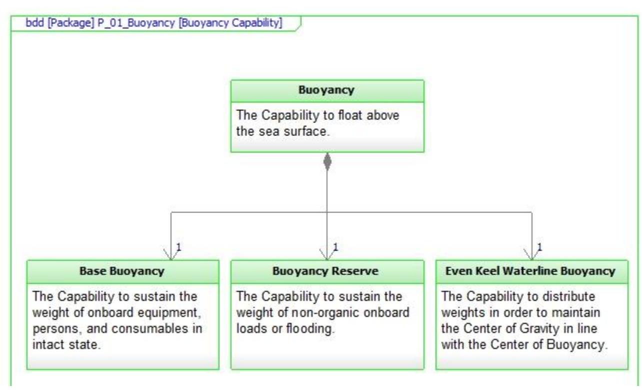

Figure 2. The Buoyancy Capability.

As evidenced in Figure 2, the Buoyancy can be further divided in “base buoyancy” and “reserve of buoyancy” as discussed in the following. A comprehensive watertight hull volume is to be guaranteed, normally able to provide “base buoyancy”, exceptionally able to provide “reserve of buoyancy” in case it is needed.

Moreover the waterline that is identified by the ship floating position should be suitable for operations i.e., the ship shall be upright and even keel (a small trim by stern can be accepted).

1) Base buoyancy

The ship capability to float is enabled by the buoyancy force (Archimedes’s law) experienced by the ship in relation with the weight of the water that the immersed hull volume displaces. The hull geometry is to be selected is such a way that the buoyancy force (directed upward) balances the total amount of weights force (directed downward) identified by the total amount of weights the ship is made up of.

2) Buoyancy reserve

It might happen however that during the ship operational life, some further accidental situations require an additional buoyancy as a reserve (i.e., the above mentioned hull water-tightness is to be guaranteed also in case of a possible draft increment).

3) Even keel waterline buoyancy

The floating position of the ship cannot be whatever. The operational profile of the ship requires suitable condition. This state can be achieved paying particular attention to the position of the centre of gravity of the ship (application point of the total weight force) and of the centre of the immersed volume (application point of the buoyancy force). Their relative position in terms of longitudinal coordinate x and transverse coordinate y generate the equilibrium waterline features.

B. Stability

Stability is the Warship’s capability to resist to inclining actions, and a further characterization is given in Figure 3.

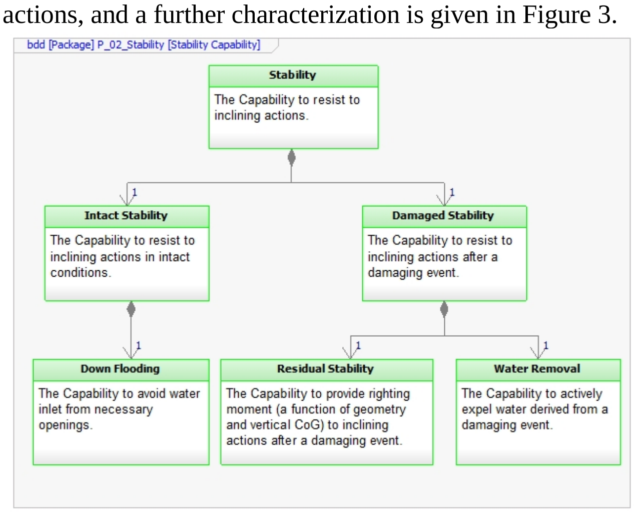

Figure 3. The Stability Capability.

The capability of the ship to resist and respond to inclining actions (e.g., wind and waves action, shift of weights, turning at speed, …) is to be guaranteed both in the intact and in the damaged condition. In the latter case often it is referred to as residual stability.

In case large heel angles are reached, some (necessary) ship openings might be immersed; this is going to further jeopardize the ship stability performance due to the possible ingress of water and due attention is to be given to the issue. (Actually, the accidental ingress of water can also jeopardize the buoyancy performance).

In the specific case of damage, the capability to pump out the flooding water might be requested as a recovery measure, to improve both residual buoyancy and residual stability.

1) Intact Stability

The capability of the ship to react to inclining actions and to return to the upright position is given by the righting moment. A satisfactory performance of ship stability is defined acting on the ship geometry and on the vertical position of the center of gravity.

2) Damaged stability

Also in case of a damaged ship, some inclining moments can act on the ship and further worsen the emergency situation. In this case, the capability of the ship to react to the inclining actions, i.e., the righting moment, is influenced by the ship flooded condition.

3) Down flooding

For the operational activity of the ships, some openings are necessary. They represent a critical point both for the intact stability and the damage stability.

An opening can be

- Unprotected
- Protected by weathertight closure
- Protected by watertight closure

In case of the intact ship, an opening can be submerged by the waterline due to a large heel angle. In this case, to eliminate the critical situation, it is enough to provide a weathertight closure (if possible).

In case of ship in damaged condition, the final waterline after a damage can reach an opening. In this case to eliminate the critical situation, it is necessary to provide a watertight closure (if possible).

4) Residual Stability

Notwithstanding a damage, a ship is requested to guarantee a residual buoyancy and a residual stability also in degraded conditions.

A specific attention is to be paid to the internal subdivision in order to manage the flooding extent and to provide the sufficient residual stability.

Different levels of residual capability can be requested, in order to resist a sufficient amount of time to wait for emergency support or to sail back home toward protected water or to maintain an operational capability.

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5) Water removal management

The water ingress due to the damage compromises the residual buoyancy capability and can be a serious threat for the residual stability, especially in case of large free surfaces.

To recover from this situation, specific systems (e.g., high capacity bilge pumps) and operational measures can be applied, to guarantee the water amount removal in reasonably short time.

Equalization systems can be also provided in order to reduce and balance the list angle after damage.

C. Structural Strength

Structural Strength is the capability to ensure the vessels structural integrity in normal and damaged conditions, as evidenced in Figure 4.

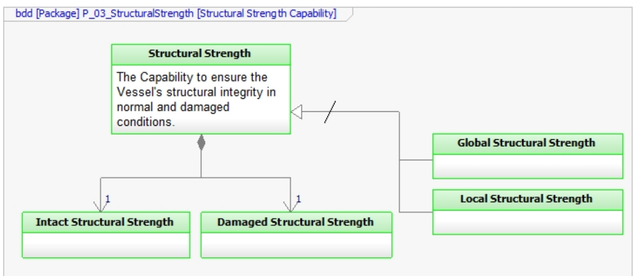

Figure 4. The Structural Strength Capability.

The ship hull and superstructures are usually built in steel and/or aluminum alloy and/or composite materials. Structure scantlings and details are to be designed in such a way that enough strength is guaranteed against local and global loads. For ships with significant length, in fact, the hull girder is characterized by global stresses that are to be properly addressed in such a way that the ship shall not suffer structural damage during her operational life in waves. At the same time, local stresses (e.g., due the presence of a crane in deck or a fluid head action on a bulkhead) are to be considered.

As already mentioned, the ship is supposed not to suffer a structural damage in operating condition, even in extremely rough seas; nevertheless an accidental damage (e.g., collision, grounding) might happen and the ship can be requested to guarantee a residual structural strength in the damaged conditions.

1) Intact Structural Strength

The ship structure (basically made of shell plates, girders and stiffeners) in operational condition is under the effect of local and global loads. The structure scantling are defined in relation with regulation requirements, which are defined with refence to safety margins, in order to avoid structural collapse and permanent deformation. Possible corrosion and fatigue effects on structures are also taken into account.

2) Damaged Structural Strength

Even though the ship is designed in order not to suffer structural damage, it may happen that for accidental events like collisions, grounding, fire, hits, the structure is damaged. A residual capability can be requested, especially as far as residual longitudinal strength is concerned, in order to resist a sufficient amount of time for emergency support or to sail in protected water or to maintain an operational capability.

3) Global Structural Strength

The ship girder is under the stress created by the weight distribution along the ship length, the buoyancy given by the submerged watertight hull, in calm water and in waves.

This is going to create, along the ship, shear forces and bending moment that are to be tackled with by the whole ship seen as a girder. In the evaluation of the ship structures able to guarantee the longitudinal strength, only longitudinal elements are to be considered.

4) Local Structural Strength

Beside the scantlings of ship structures in charge of sustaining the longitudinal strength, also assessment at local level are to be carried out (e.g., the scantling of transverse bulkheads), with specific reference to local loads.

D. Controllability

Controllability is the capability to control the vessels speed and heading in order to accomplish a defined objective, as described in Figure 5.

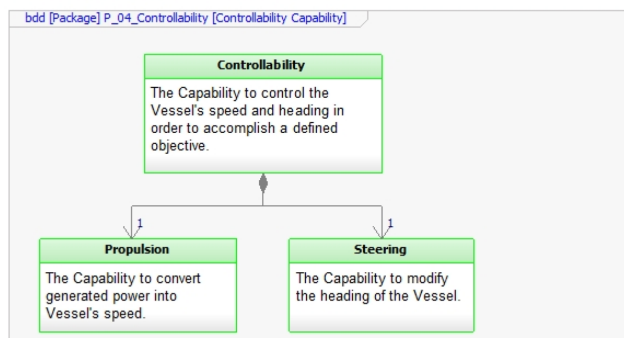

Figure 5. The Controllability Capability.

The ship is assumed able to sail at the desired speed, with the capability to arrange the suitable route, even in heavy adverse environmental conditions.

1) Propulsion

The capability to use the generated power to produce thrust and therefore ship speed is usually obtained by means of a propulsion system like shaft lines with propellers. Other possible propulsion devices, not very much common for naval ships applications actually, are pump-jets, Voith-Schneider systems, azipods.

2) Steering

In the traditional solution where shaft lines and propellers are used, the ship maneuvering is guaranteed by rudders controlled by steering systems, in the stern part of the ship.

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The other above mentioned propulsion systems are intrinsically provided with a steering devices.

The proper maneuvering of ships in restricted water can be supplemented also by bow and stern thrusters placed in the symmetry plan of the ship.

E. Power Generation

Power Generation is capability to generate power for the entire vessel including all organic equipment, and it can be further discussed as represented in Figure 6.

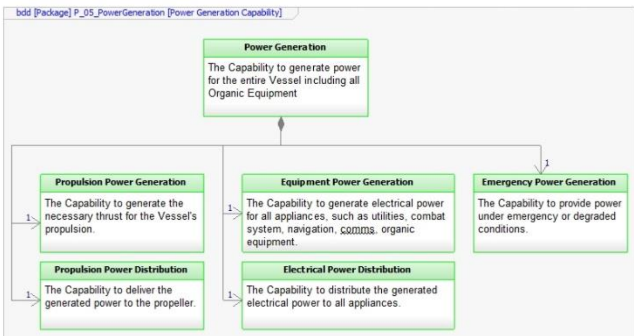

Figure 6. The Power Generation Capability.

A sufficient amount of power generation on board is to be guaranteed in order to provide the ship propulsion and to provide support for all the other possible electrical load requests onboard.

In naval ships the distribution of power generation systems onboard is requested to be adequate to provide energy to the ship also in a residual mode in degraded condition after a damage. Also in this case (see residual buoyancy, stability, structural strength) different levels of residual power generation can be requested after the damage, in relation with the capability to resist waiting for emergency support, to sail in protected waters, to express a residual operational capability.

1) Propulsion Power Generation

The typical power generation system on board navy ships in made of diesel engines and gas turbines with several possible combinations. These are properly able to provide power for propulsion in relation with the power distribution systems described later. In some cases also electrical engines are used for the propulsion and the power supply is guaranteed by the electrical power distribution system, properly powered.

2) Propulsion Power Distribution

In general, the propulsion power distribution is guaranteed by a gear box/boxes (more or less complex in relation with the number and the typology of the power generator units) and shaft lines, provided with appropriate joints and bearings.

3) Equipment Power Generation

Shipboard power is generated using prime movers and an alternators working together. Typically diesel generators are used on board in the sufficient number to provide the necessary power, enough flexibly and redundancy.

In some cases the alternators are able to derive power from the main propulsion shaft lines of the ship.

4) Electrical Power Distribution

The electrical power distribution is to be guaranteed with the proper technical characteristic (e.g., voltage and frequency) in relation with the final electrical users.

Beside the power generation units, the propulsion power distribution systems is made of main switch board, bus bars , circuit breakers, transformers, wires and cables. The distribution systems is designed in such a way to provide redundancy and reliability.

5) Emergency power Generations

It can be requested to provide an emergency power generation for supply in case of ship total black out. The size is selected making reference to the selected electrical load requests that are to be guaranteed in emergency situation.

F. Safety

Safety is the capability to achieve and maintain a state in which all embarked persons, tangible properties interacting with the vessel and the environment surrounding the vessel are free from risk. This definition is also shown in Figure 7.

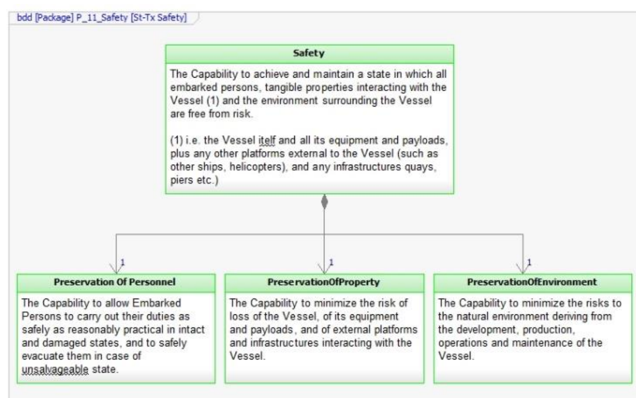

Figure 7. The Safety Capability.

Safety is generally meant as a freedom from risk. In the case this is impracticable, it can be accepted to focus on the reduction of risk at a level as low as reasonably possible. In this perspective, attention is paid on both the probability of occurrence of an hazardous event and on the severity of its consequences. It is important to point out that the loss (total or partial loss) is the result of an hazardous situation that in a specific scenario has evolved in a loss. Since it may be difficult to foresee an unexpected scenario, it is difficult to have control on it. Therefore during the design process, the attention is more focused on the hazard identification and relevant avoidance or countermeasures.

1) Preservation of Personnel

The safety of life at sea has not been the same along the history and still now it is not practically the same all around the world. Nevertheless at present this is a very well addressed issue by means of application of the most demanding international safety rules. In the merchant ships context, the SOLAS convention is the most important IMO international safety rule and it prescribes, among others, requirements for residual buoyancy and stability, fire fighting, evacuation and life saving appliances, dangerous goods transportation, safe management of ships.

It is important to point out that the ship safety is meant as the safety of the system and not as professional safety that is ruled by other international conventions (STCW, MCL2006)

2) Preservation of Environment

Attention on the effect of ship navigation on the environment is rooted in the seventies of the twentieth century. The most important international regulation is the MARPOL convention, developed by IMO, often used as a reference for the navy fleets, where appropriate.

At first, the attention was only on the sea pollution (e.g., due to oil leakage, sludge water, garbage) but recently the attention is very much on the air pollution relevant to the engines exhaust gases (MARPOL annex VI)

3) Preservation of Property

This aspect is not explicit in the safety regulation, but it is implied in the concept of safety of life at sea that in any case has the priority.

The attention to the preservation of property is reasonable due to the huge economical value of a ship (e.g., several hundreds of millions of dollars), but it is even more sensible in case of naval ships that usually have an even higher value and financially supported by public money.

G. Navigation

As evidenced in Figure 8, **Navigation** is the capability to perform Warship positioning and route planning, and to monitor and control the Warship's adherence to the planned route.

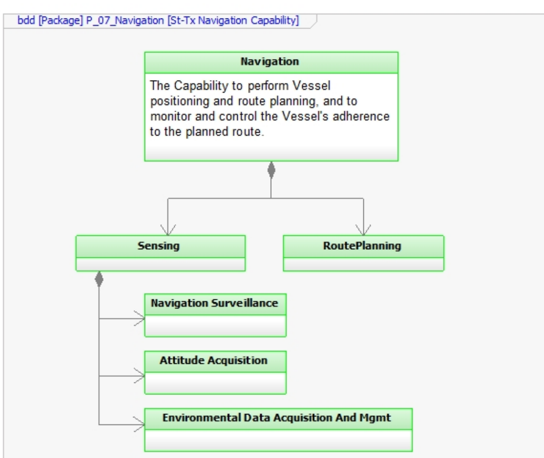

Figure 8. The Navigation Capability.

Two main elements compose the Navigation capability: Sensing and Route planning:

1) Sensing

Sensing is the capability to acquire information about the Warship position, heading, motion and attitude, and the operational environment (both natural and tactical) surrounding it. In detail, the Sensing capability is composed by other specific capabilities:

- **Navigation Surveillance** refers to the detection, localization, recognition/classification and tracking of external sea surface contacts
- **Attitude Acquisition** refers to the precise determination of the tilts of the Warship's frame with respect to "local" coordinate axes. This capability is tightly connected to the Warship performance, for example, successful missiles launch, or successful detection and tracking of missile threats are deeply influenced by precise attitude data acquisition.
- **Environmental Data Acquisition and Management** refers to the capability to perform data acquisition about meteorological and marine/oceanographic environment surrounding the Warship and about its global position and reference time.

2) Route Planning

Route Planning refers to the capability to plan and establish the Warship route. Wind, waves and currents and sea ice cover are crucial factors in choosing a route at sea. Advanced routing systems support the crucial decisions about the route. Avoiding hostile entities or rough weather and having the best possible advance route planning can minimize damage and allow more precise control of the Warship. Choosing the optimum route also lays the foundation for reducing fuel consumption. All these aspects highlight the importance of the Route Planning Capability.

H. Command and Control

Command and Control is the Capability to allow the operators to perform full control of the Warship's equipment, in order to optimize the tactical use of the Warship within its naval task force. Further details to this regard are given in Figure 9.

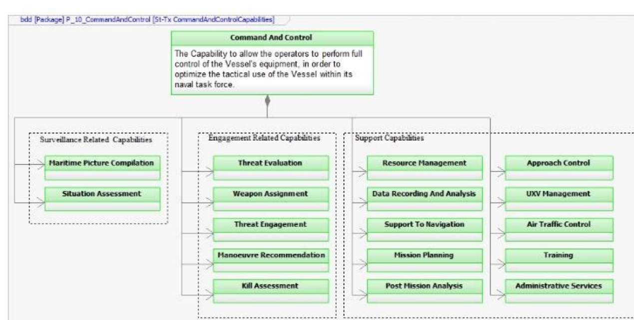

Figure 9. The Command and Control Capability.

Command and Control (C2) includes a wide range of specific capabilities, which can be grouped in the following broad categories: “Surveillance”, “Engagement” and “Support”, as described below.

1) C2 Surveillance Related Capabilities

Maritime Picture Compilation is the Capability to process the data received from passive and active sensors, from Data Links and from manual insertion by Operators. The scope is to display to the Operator a unique representation of the Real World Objects (RWOs) around the Warship.

Situation Assessment is the Capability to identify and to classify any tracks in the maritime picture as friends or possible threats. Many track functionalities for identification are necessary: initialization, association, coupling, splitting, merging etc.

2) C2 Engagement Related Capabilities

Capabilities dedicated to the management of potential threats around the unit and the coordination of any reactions.

Threat Evaluation is the Capability to evaluate threats and set priority levels in their engagement.

Weapon Assignment is the Capability to identify the suitable weapon system to use against given threats. The reaction must be coherent with kinematics features, doctrine elements, threat category, weapon system limitations.

Threat Engagement is the Capability to perform engagements against given threats through the identified weapon systems. Typically an Engagement Plan is defined with a detailed schedule of reactions, and adaptation margins to handle unpredicted situations.

Manoeuvre Recommendation is the Capability to recommend the motions and attitude the Warship should assume during an engagement in order to minimize the vulnerability against a specific threat.

Kill Assessment is the Capability to evaluate the result of the neutralization action on an engaged threat, based on data acquired from sensors, telemetries in downlink from the used weapon when available, or operator manual inputs.

3) C2 Support Capabilities

Resource Management is the Capability to monitor and control the status of organic equipment, including the management of alarms and the control of electromagnetic emissions.

Data Recording and Analysis is the Capability to store, extract and process data exchanged among all Warship equipment.

Support to Navigation is the Capability to support safe navigation of the Warship through navigation aids management.

Mission Planning is the capability to define mission parameters and relevant data for the Warship.

Post Mission Analysis is the Capability to analyze mission recorded data for the purpose of validating actions taken during the tactical phase, potentially generating new contact data based on discovered missed detection/ classification opportunities.

Approach Control is the Capability to support aircraft operations, including approach, deck landing and take off.

UXV Management is the Capability to manage Unmanned Aerial, Surface or Underwater Vehicles operations.

Air Traffic Control is the capability to direct air traffic in coordination with ATC centers.

Training is the Capability to simulate possible scenarios in which the Warship could be involved in order to support Operator training.

Administrative Services is the Capability to provide administrative services such as mail, intranet, data processing, printing facilities etc.

I. Communications

As better detailed is Figure 10, **Communications** is the Capability to manage the exchanges of information both internally among the Warship components, and with other units or land centers to receive data and orders and participate as a force asset.

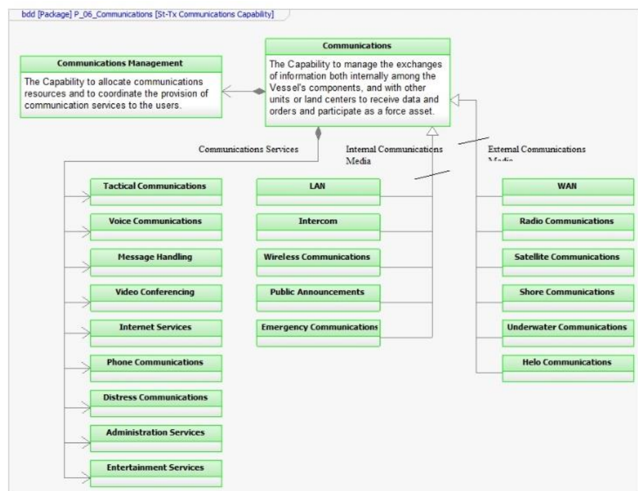

Figure 10. The Communications Capability.

The first relevant component of this Capability is **Communications Management**, the Capability to allocate communications resources and to coordinate the provision of communication services to the users.

Following, Communications can be categorized according to the type of Service that is conveyed (voice, data, entertainment, etc.), and the media through which the services are delivered, both internally on the Warship, and externally.

1) Communications Services

The following Services are typically delivered by the internal and external communications networks:

- **Tactical Communications**
- **Voice Communications**
- **Message Handling**
- **Video Conferencing**
- **Internet Services**

- **Phone Communications**
- **Distress Communications**
- **Administration Services**
- **Entertainment Services**

2) Internal Communications Media

The following list reports the typical Internal Media through which the communication services are delivered:

- **Local Area Networn (LAN)**
- **Intercom**
- **Wireless Communications**
- **Public Announcements**
- **Emergency Communications**

3) Internal Communications Media

The following list reports the typical External Media through which the communication services are delivered:

- **Wide Area Networn (WAN)**
- **Radio Communications**
- **Satellite Communications**
- **Shore Communications**
- **Underwater Communications**
- **Helo Communications**

J. Surveillance

Surveillance is the Capability to detect, localize, recognize and classify and track contacts in all domains related to the Warship's Area of Operations, as shown in Figure 11.

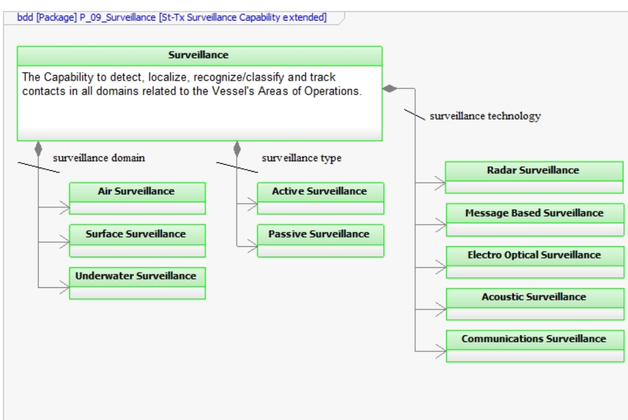

Figure 11. The Surveillance Capability.

Based on the Surveillance domains, types and employed technology, three different categorizations can be made:

1) Surveillance domain

The Surveillance Capabilities are related to the Aerial, Sea Surface or Underwater domains:

Air Surveillance allows detecting air based objects such as aircrafts, or missiles.

Surface Surveillance allows detecting objects on the surface of sea, lakes, oceans or located near the coast.

Underwater Surveillance allows detecting underwater objects, such as submarines or mines.

2) Surveillance Type

Active Surveillance is performed involves the emission of signals, typically in the form of electromagnetic or acoustic waves. Exploiting this capability, the Warship can cover a wide range of kilometers in the domain where detecting occurs. The drawback of the active surveillance consists in being more visible and easily discovered by other entities.

Passive Surveillance on the other hand is performed by receiving signals emitted by other systems but not issuing any interrogation. Lesser performance in sensitivity and range of the detection is traded off by the ability to remain more effectively hidden from enemy detection.

3) Surveillance Technology

This categorization is related to the technology employed to perform the Surveillance activities.

Radar Based Surveillance allows the Warship to detect both fast and slowly moving non-cooperating objects, through the acquisition of their radar echo. Their position and velocity are determined using distance and azimuth information for 2D radar surveillance, and also with elevation for 3D radar surveillance.

Message Based Surveillance is performed through the exchange of coded messages for the mutual exchange of identity and voyage related information, and is implemented using base stations and transponders. Typical examples of message based surveillance are Interrogation Friend or Foe (IFF), used for determining the identity of an unknown contact on the basis of the response to a direct interrogation message, and the AIS, a relay network connecting all commercial and military vessels on the VHF Maritime Mobile Band, carrying information such as departure and destination ports, transported cargo or precise positioning.

Electro Optical Based Surveillance consists in the optical and infrared spectrum scanning through high performance cameras, able to operate both during day and night and in all possible weather conditions.

Acoustic Based Surveillance allows the Warship to detect underwater objects, through the acquisition of their acoustic echo. Acoustic surveillance makes use of several types of sonar sensors, either active or passive, and which can be installed directly attached to the hull, or as arrays of multiple elements towed by cable.

Communication Based Surveillance consists in performing analysis on emissions from radio channels in order to achieve information related to the source, such as the relative direction of emission, the type of equipment used for transmission, or even the gathering of intelligence based on the content of the communications.

K. Combat

Combat is the Warship Capability of denying the enemy the effective use of threats against the Warship itself, its protected assets, or tactical/operational/strategic interests.

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More details are schematically provided in Figure 12.

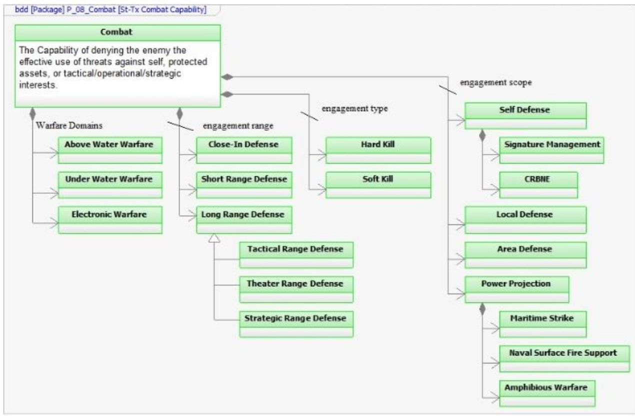

Figure 12. The Combat Capability.

There are four main categorizations of the Combat Capability, starting from the warfare domain to which a given threat belongs, to the type, scope and range of the engagement that is required to neutralize such threat.

1) Warfare Domain/Area

The warfare Domain is related to the environment to which the threat to be faced belongs:

- **Above Water Warfare** concerns threats that originate above the water surface, and is divided in two Warfare Areas: Anti Air Warfare (AAW), including threats such as airplanes, missiles, or helicopters; and Anti Surface Warfare (ASuW), including threats such as ships or land based platforms
- **Below Water Warfare** concerns threats that originate below the water surface, and is divided in two main Areas: Anti Submarine Warfare (ASW) and Mine Warfare (MW)
- **Electronic Warfare** (EW) concerns threats that affect the electromagnetic spectrum, independently from the physical domain of their bearer. EW is further characterized by Electronic Attack Measures, and Electronic Protection Measures

2) Engagement type

Two types of Engagement can be performed by the weapons carried on board the Warship:

- **Hard Kill**, when the weapons physically engage threats by destroying/altering their payload/ warhead in such a way that the intended effect on the target is severely impeded
- **Soft Kill**, when the weapons alter the electromagnetic, acoustic or other signature(s) of a target thereby altering the tracking and sensing behavior of an incoming threat

3) Engagement range

Entirely different weapons are devoted to the facing of threats according to their range:

- **Close In Defense** relates to the neutralization of threats within a few Nautical Miles (NM) from the Warship, and is typically performed with small caliber artillery
- **Short Range Defense** relates to the neutralization of threats within tens of NM, and is typically performed with large caliber artillery, missile systems, torpedoes and so on
- **Long Range Defense** relates to the neutralization of threats within several thousands of NM from the protected asset; Long Range is further divided in Tactical Range (12-50 NM), Theater Range (up to several hundred NM), Strategic Range (up to national or regional range)

4) Engagement scope

Engagement Scope regards the definition of the asset(s) that the Warship is assigned, by a specific mission, to protect:

- **Self Defense** is concerned with avoiding/neutralizing threats against the Warship itself, and includes other capabilities, such as Signature Management and CBRNE (the Capability to resist to Chemical, Bacteriological, Radioactive, Nuclear or Explosive threats)
- **Local Defense** is concerned with the neutralization of threats against a protected asset (High Value Unit, HVU), such as another ship within the same convoy, or a port
- **Area Defense** is concerned with the neutralization of threats against a specific protected geographical area, such as a Sea Line Of Communications (SLOC)
- Finally, **Power Projection** is devoted to the protection of strategic level interests, by actively employing force against enemy assets, and is further divided in Maritime Strike when the target is naval, Naval Surface Fire Support (NSFS) when the target is land based, and Amphibious Warfare when the contribute of the Warship is essentially logistic

IV. CAPABILITIES INTERDEPENDENCIES

The thorough description of all Whole Warship related Capabilities can be followed by a discussion on mutual interactions and interdependency. For example the Surveillance Capability can be enhanced by increasing the Radar's height, however this will have a direct impact on the Warship's Stability; or at the same time, optimizing Surveillance will have an impact on the Warship's Controllability in terms of required Power Generation. This in turn will affect the Buoyancy due to the different weight of the power generators.

These considerations become really effective when all Capabilities are taken into account comprehensively at the same time, allowing an holistic view of the entire Warship as a whole in its operational environment. This type of effort will be the objective of future works based on the findings presented in this paper.

V. CONCLUSIONS

In the paper it is postulated that, during the design process of complex Warships, a shift of attention is necessary to an initial activity of thorough analysis focused on the problem domain. Thus, the approach shifts the focus on the level of the whole warship's capabilities, rather than on its components and subsystems that belongs to the solution domain.

A set of twelve Capabilities characterizing the naval vessel has been proposed, further detailed and commented. Their identification enables and instructs the investigation and development of the solution domain. They are assumed to be effective to comprehensively represent all the necessary Capabilities for the Warship to fulfill a superior mission by means of proper implementation of the operational requirements.

All the identified Capabilities are meant as Warship emergent properties deriving from the successful and concurrent interaction among the different parts and systems. In this perspective, an overcoming of the typical separation between the Warship platform and the Warship combat systems is pursued.

As a further step it will be possible to discuss how the different Capabilities are related to each other and with the Warships technical characteristics as well. In this perspective the relation of the contents of this paper and the traditional naval ship design process is elucidated: the traditional design spiral provides an effective model for the assessment and the relevant discussion.

The Capability formulation enables also:

- the systematic identification of the necessary technology to be installed onboard with specific reference to their interfaces and interference characteristics with the ship platform.
- the identification of workable Measures of Effectiveness and derived Measures of Performance, to afterwards give evidence of the Warship compliance with design goals.

In conclusion the content of this paper represents a proposal to better set out the naval ship design process since the very beginning for a comprehensive and robust final fulfilling of the customer needs following a documented and informed process.

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