# Containers as a Weapon I

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## Synopsis

Future warships will almost certainly be designed around a requirement set that necessitate fast paced, evolving and multi-role capability deployment to maximise utility and cost effectiveness for the end user. This will require a flexible and potentially simpler platform that relies upon modularity – being capable of being re-rolled to a variety of mission types and fit to receive technology or capability insertions throughout their service lives.

The UK MOD, through the Type 26 and Type 31 programmes has committed to the modularity concept through the adoption of mission bays. These mission bays can be configured around a variety of: boats, unmanned systems, or equipment and systems integrated into standard ISO shipping containers or other military modular systems. These containerised systems are termed as mission modules. Types 31 and 26 respectively, alongside numerous platforms in service with NATO partners, feature provision for these mission modules.

Vessels such as Type 31, or future cost effective escort platforms will feature mechanical power & propulsion systems. Previous iterations of Engine As A Weapon have focussed on sophisticated, all-electric propulsion topologies and cite these as the key enabler to future weapons and sensors.

With the UK MOD concurrently committing to Laser Directed-Energy-Weapons (LDEW) through the DragonFire programme it is apparent that future vessels will need to be capable of fielding this, or similar systems despite the previously cited constraints of mechanically based power & propulsion architecture. The possibility also exists that such LDEW systems could replace or augment current Close-In-Weapon-Systems such as Phalanx on current, or near future vessels.

This paper will consider the above by exploring the opportunities and constraints of utilising the volume offered within a study vessel's mission bay to host systems that enable LDEW deployment. The mission bay on these vessels can be configured around large, containerised batteries which, when configured with adequate cooling and combat system integration could enable the retrofit of DEW systems. A high level analysis of the impact assessment on the host platform has been made and is compared against the more typical approach of satisfying the needs of new capabilities via the consumption of margins from the vessel's platform systems.

**Keywords:** Laser Weapon, Power and Propulsion, Battery Technology, Mission Bay

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## 1. Introduction

In 2023, surface ships that feature mechanical power and propulsion systems still form the backbone of most of the worlds naval fleets. With the notable exception of the Royal Navy, the Navies of the United States, Japan, Republic of Korea, and numerous European countries all feature escort class vessels constructed around mechanical propulsion plants with a separate, diesel or gas turbine power generation system[1]. The generator sets in these systems typically satisfy the base electrical loads of the vessel, be that Heating, Ventilation and Air Conditioning (HVAC) systems, Chilled Water systems, or Combat System loads[2].

One of the long-standing aims of the Engine As A Weapon conference is to discuss the inherent advantages of electrification; combining the requirements to satisfy both propulsion load and base electrical load into one combined system. Increasing electrification within naval vessels has culminated in Integrated Full Electric Propulsion (IFEP) or Integrated Power Systems (IPS) being fielded on vessels including the UK Royal Navy's Type 45 Destroyer and the DDG1000 Zumwalt Class Destroyers of the US Navy.

For the vast majority of navy's, mechanically propelled vessels remain an option for their near-term naval procurement decisions due to their inherent simplicity in operation and maintenance. Increased duration deployments require a navy to put their crew at the heart of the support solution to operate, maintain, diagnose and repair without OEM intervention at sea.

However, the service life of these vessels alongside the rapid advancement of technology mean that these mechanical ships will still need to field power hungry sensors and effectors that are yet to be developed. A key example is the near future deployment of Laser Directed Energy Weapon (LDEW) systems[3].

Concurrently, one of the key trends in modern naval vessel construction is the provision of spatial margins in the form of large mission bays. These mission spaces feature supplies for hotel services, lifting and handling solutions as well as optimised ingress/egress routes to fleet new systems and equipment. This allows a vessel to accept new, often modular or containerised capabilities during short support periods.

This paper considers the above and aims to determine the feasibility of a candidate mechanically powered vessel's ability to accept future electrical loads such as LDEW within the service life of vessels procured today (i.e. 15-20 years). The author assesses the capability of the ship's onboard power generation system alongside utilisation of the ships mission bay to host Containerised Battery Systems to satisfy this requirement. The consideration for physical and functional integration of the capability are reviewed.

## 2. Future Loads – LDEW Systems

In 2017, the UK Ministry of Defence launched the DragonFire LDEW technology demonstrator programme. It sought to assess the feasibility of deploying High Energy Laser (HEL) systems in the near term to compliment existing Close In Weapons Systems (CIWS) and to tackle asymmetric threats such as Unmanned Surface Vessels (USVs).

Whilst such systems could be fitted to future escort vessels such as the Type 83 solution[4] the potential exists that similar LDEW systems may also be retrofitted to the mechanical vessels being procured today.

According to public domain information the DragonFire system will feature a HEL with a beam power in the 50kW class[5]. However, similar HEL systems have been fielded on test beds and operational platforms between 100 - 150kW[6] as part of a 'laser layered defence system'[7].

In addition to the HEL, the LDEW system will have a range of other load requirements to facilitate its operation[8]. Figure 1 below shows a schematic representation of the LDEW system and its key supporting systems. Future vessels should not only be able to accept the power generation requirements of such a system but also the manner in which that power is to be delivered alongside a thermal management solution.

Based on available public domain information of in development LDEW systems, a laser of beam power circa 150kW has been assumed as a realistic basis for this study[3]. This would yield a total power demand for the HEL of 600kW assuming a 25% efficiency[3,7]. Due to the nature of LDEW systems, the power required for the HEL will be delivered as a pulse in the form of a square load demand. This will feature an immediate ramp from 0kW to 600kW.

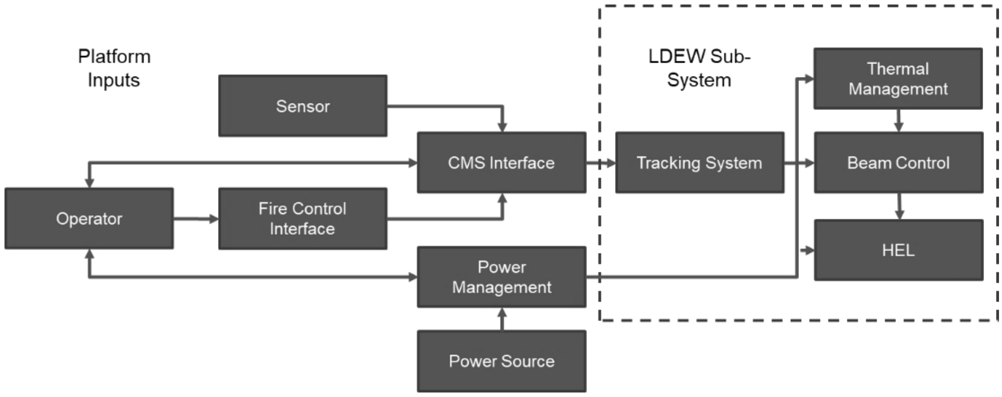


Figure 1 – Key sub-systems in a notional LDEW system

Additional electrical power will also be required to support the LDEW system's ancillaries with a further demand placed, potentially, on the ships chilled water systems for additional elements of the thermal management solution. It is assumed that these ancillary loads will be less transient in nature and, as such, place an enduring, steady-state load on the platform's power generation system.

It is assumed that all relevant LV loads will need to be satisfied to a determined Quality of Power Supply (QPS) that is governed by STANAG1008. This standard prescribes maximum permanent and transient tolerances for frequency variation across the power distribution system – ensuring that sensitive LV consumers operate as per intent. This applies particularly to a vessel's combat management system but also platform systems. It is assumed that any ancillary loads required by the LDEW system should also be satisfied in accordance with STANAG 1008[12].

## 3. Candidate vessel

The candidate vessel will be circa 140m in length and feature an all-diesel engine propulsion plant alongside a diesel generator-based power generation system. For this study, the power generation system architecture will feature a 440VAC low voltage electrical distribution system configurated across two main switchboards with an interconnecting bus tie linking the two. There will be 4 off. diesel generators each rated at 1000kWb producing circa 900kWe.

The candidate power system is a well proven and popular topology for mechanical naval vessels – a representative single line diagram (SLD) is shown below in Figure 2.

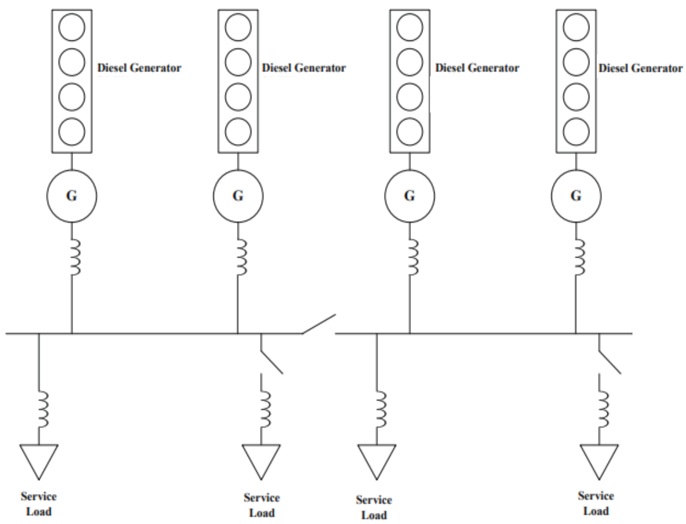


Figure 2 – Candidate power system architecture

The vessel will also feature a mission bay capable of accepting 6 off. standard 20 ft ISO Shipping containers (TEU).

## 4. Implications of leveraging Vessel LV Power on System CONOPS

If we consider the vessel requirement of generating suitable electrical load for LDEW, platform and combat systems alongside STANAG1008 QPS requirements, a number of assumptions can be made in relation to how the LV system is operated.

During the command posture in which the vessel will operate the LDEW, it is assumed that the base electrical load will be circa 1000kWe supplying all required platform and combat systems. During State 1 operations (Action Stations) the LV system would typically be run in a configuration that maximises redundancy. Three generators (allowing one to be out of action as per typical N+1 requirements) would be in operation, with two providing the main load. The third generator unit would be providing standby power in event of generator trip or battle damage. The bus tie would be open to enable a 'twin-island' mode; safeguarding against the loss of a switchboard.

The requirement to satisfy LDEW loads introduces a requirement to the system that the CONOPS above would not be able to meet. It is beneficial to segregate any negative effects of the pulse load from the ship's systems. Such negative effects cited would include QPS fluctuations including frequency or voltage deviations or harmonics. As such we can assume that one generator and switchboard will service the need of the LDEW[9]. With two remaining generators available there are limitations on available LV configurations that provide resilient operation.

A feasible configuration would be where 2 off. 900kWe generators supplied a single switchboard dedicated to the supply of the non-LDEW consumers. The Diesel Generators on this switchboard would see a 56% MCR demand on each unit - offering suitable spinning reserve to enable resilient LV system operation. However, it is noteworthy that a single generator unit would not be able to sustain the ship's load without the need to shed load. Once all non-critical loads are shed, the single generator will be capable of sustaining the remaining vessel load for a period to enable another generator to be bought online.

In this instance, the vessel is effectively running all ship services in a 'single island' mode. This will leave 2 off. 900kWe units on the remaining LV switchboard – where one dedicated generator can supply the LDEWs HEL. This generator would also be responsible for supplying all base ancillary loads to the LDEW.

Prior studies by Mills et al[9] show this configuration to be beneficial for the generator and switchboard supplying the LDEW. Placing a 10-25% enduring base load (i.e. LDEW ancillary loads) on the generator that feeds the LDEW increases the unit's ability to handle load steps whilst maintaining the systems compliance against the STANG 1008 limits[9].

Therefore, for the candidate vessel, the LDEW and wider ship service loads are powered in accordance with the diagram below in Figure 3.

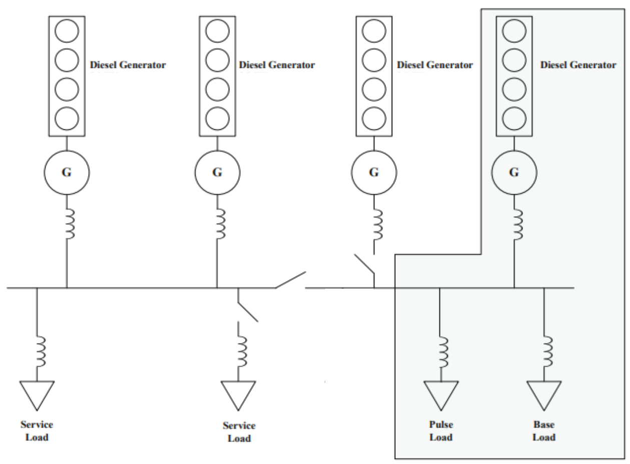


Figure 3 – Envisaged generator utilisation for LDEW operation[9]

Based on the conclusions drawn from Mills et al, a mechanical ship in this configuration, and with these LV CONOPS could be capable of fielding a single LDEW system[9]. This is caveated by the need for further study and vessel specific electrical systems modelling.

For the purpose of this study, and with the caveat that further investigation is required, it would appear possible based on previous literature[9] that functional integration of the LDEW within a conventional, mechanically powered ship's LV system could be possible. However, the LV System configuration could be considered as less resilient with a reduced capability of accepting damage or equipment unavailability.

Prior studies have also only considered the electrical system performance and that systems ability to satisfy the load demand. If we consider the LDEW demand as a 600kWe load against the 900kWe rated generator, a requirement exists on the specified generator unit to accept load steps of up to 66% of the unit's rating. This has the potential to cause issues with the mechanical component of the generator unit. As such, an optimal solution to both physically and functionally integrating an LDEW depends on a number of system and platform level factors.

## 5. Drawbacks of utilising the vessels Power Generation System

There are a number of qualitative implications that should be considered when assessing the best method of satisfying the LDEW demand. As such, the implications to utilising the LV system to satisfy the LDEW demand should be explored. These can be summarised below;

- Reduction to DG Mean Time Between Overhaul (MTBO) or increased maintenance caused by sustained, high cyclic load on a mechanical prime mover,
- Increased spare parts consumption and greater Through Life Costs of the associated Diesel Generators– reducing the benefit of 'low cost per shot' of LDEW,
- Reduced flexibility in LV switchboard configurations or a change in LV plant line up in each threat state (i.e. loss of 'twin island' mode in State 1 operations) as discussed,
- Reduced ability to accept the loss of a single switchboard due to fire, damage or equipment unavailability
- The impact of functionally integrating the solution to the current LV system
- Degradation or erosion of power generation margins that could be utilised to satisfy another requirement,
- Any subsequent physical integration challenge of large and/or high mass power electronics, filters or protection devices that will need to be sited in current electrical spaces/cabinets onboard.

Whilst it can be concluded that the candidate vessel could satisfy LDEW load demands, an alternative approach can be considered.

## 6. Thinking Outside (or inside) the Box

Given the compromises made to the vessel's power generation systems when operating LDEW it could be advantageous to segregate the requirement for sustaining the vessel's electrical load from the LDEW load. This segregation could be achieved using the volume available in the vessel's mission bay to fit Containerised Battery Modules (CBM); effectively creating a large *'magazine'* of electrical power whose role is to solely supply the LDEW systems. Such systems are built around Lithium-Ion battery units, capable of the deep-discharge required to satisfy LDEW loads and are available in the commercial marine market as Commercial Off The Shelf (COTS) items.

When retrofitting the LDEW, either as a temporary fitment (such as Military Tasking Equipment (MTE)) for a specific mission, or as a permanent Alteration & Addition (A&A) managing both the physical and functional impact on the configured design baseline is important.

As such, reducing engineering change of the platform to facilitate LDEW integration is prudent and will ease installation, reduce the design effort and result in schedule and cost benefits. Such advantages could enable the fitment of the LDEW during a scheduled short duration maintenance period such as Fleet Time Support Period (FTSP).


Figure 4 – Notional COTS Containerised Battery Module[13] (image courtesy of Wartsila)

When considering the positive effect this would have on the vessel we can consider:

- Minimise modification to systems and equipment that are situated in spaces that feature large degrees of work in way (WiW). This will enable rapid installation and enable a 'fail-fast' approach,
- No change to the on-board LV Electrical system - experience in delivering the Type 23 Power Generation and Machinery Control and Automation (MCAS) System Upgrade (PGMU) highlight such programmes as a cost and schedule driver to a deep maintenance period,
- The CBM are self-contained and removable. These units can be exchanged in port to enable all maintenance to be conducted offboard by the OEM or skilled operator/maintainers,
- Offboard charging could see the units being charged utilising renewable power resulting in a zero emissions LDEW capability,
- An increased ability to respond to technological change. These units can be refreshed as battery or power electronics technology improves,
- Increased ability to retrofit to older or less complex ships, potentially at reach during an FTSP,
- 'Magazine' capacity can be increased or decreased based on mission demands or other mission modules that need to reside within the Mission Bay.
- Enabler of the Royal Navy's MarOpC Thematic Modularity Concept; by focussing on 'Podular' capability the RN, or other operators, can transition to LDEW capability 'at pace' [10,11]
- Ability to leverage COTS technology that is proven in parallel industry; thus, reducing risk.

With the concept outlined above, a simple single line diagram (SLD) can be assumed. Figure 5 provides a notional SLD with the vessels LV power generation system continuing to satisfy all platform loads.

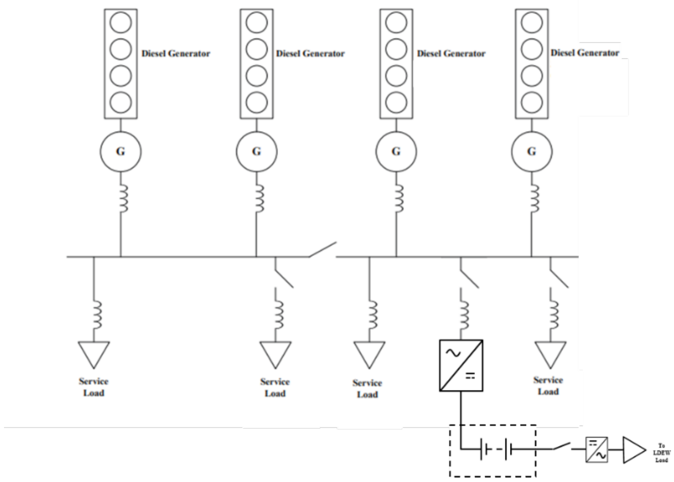


Figure 5 – Nominal SLD of the expanded LV system

To provide greater flexibility and more enduring capacity, the battery system can be fed from the ships supply via the standardised LV Power connection that would reside within the mission bay. This should be specified to the requirements within ANEP-99 Design and Interface Standards For Containerised Mission Modules to ease integration.

This LV Power supply would be the sole interface to vessel generated power and would be utilised to charge the CBM in lower threat states. This effectively limits the 'magazine' size of the LDEW only by the fuel bunkerage onboard – however, weapon availability will be constrained by battery charge time and the availability of power in the LV system to charge the battery. As such, adequate CBM sizing studies must be undertaken dependent on the usage profile of the weapon.

Exporting of power from the CBM to the vessels LV Power Distribution system has not been considered due to the increasing complexity of the LV system, its control and its CONOPS. This would potentially erode the benefits gained through the adoption of simplicity.

## 7. Integration Considerations

As referenced, the design of the CBM and platform interfaces should follow common standards such as ANEP-99 to de-risk interfaces and simplify the integration process. This may require liaison with the CBM OEM and could cause a deviation from the COTS solution. The physical interfaces with the platform are primarily securing locations and LV power. However, the following should be considered:

***Volume, Weight and Stability***

The CBM currently on the market are circa 15 tonnes in mass for a roughly 750kWh capacity or around 27 tonnes for a 1.5MWh unit[13]. These modules are configured around 10ft and 20ft containers respectively and are of ISO standard dimensions.

Whilst the envelope of the module is unlikely to pose an integration risk given the space provision of the mission bay, careful management of weight margins will be required. In the loaded condition the mission bay has the potential to alter centres and stability margins on the platform; not least considering module weights in excess of 20 tonnes.

With other mission modules potentially residing within the mission bay at the same time, each with their own weight and volume characteristics, investigations will need to be undertaken to determine the optimal mission bay layout. Consideration needs to be made for how this impact is quantified and managed, options include:

- Imposing limits during the procurement of the CBM (or alternative 'mission modules') for weight and centre of gravity
- Derive pre-determined configurations and layouts of mission modules for which the weight and stability calculations have already be assessed to assist in platform integration.
- Undertake dynamic calculations for each configuration considering tank levels and trim, as is standard practice on container vessels

In summary, the impact of changing the configuration of mission modules needs to be considered at the platform level, as part of the weight and stability margin.

The LDEW effector will need to be placed on the top side of the vessel to maximise its arcs of fire. A nominal standalone LDEW system could be in the region of 10 tonnes[8]. As such up to date information contained within the vessels weight books alongside adequate provision of capability upgrade margins will need to be considered during the vessels design to facilitate integration.

***Mission Bay Considerations***

The location of the CBM will be dependent on the location of the mission bay within the vessel's general arrangement. However, it should be noted that the inclusion of the CBM within the mission bay will impact the platform safety case. This problem has been considered in the deployment of Li-Ion units in submarines; as such a number of learning from experience (LfE) topics can be applied.

Deployment of large Lithium-Ion battery stores pose a series of risks which necessitates a number of considerations for the mission bay layout. Firstly, the location of the mission bay should minimise the effects of, or indeed the likelihood of fire. The CBM should be placed away from living quarters, the aviation deck or helo fuelling facilities and magazines. As such, this presents a driver for vessel design – potentially limiting either the location of a mission bay, or the adoption of CBMs for vessels currently in-service that feature mission bays in problematic areas. The location of the Mission Bay space should also enable good ventilation; outside of the vessels citadel to promote the dissipation of potentially flammable gases to atmosphere that are caused by BCM charging.

A fire-suppression solution needs to be considered. Two options exist; either place a requirement onto the OEM to integrate such a system within the BCM unit, or integrate a fixed fire fighting system within the mission bay. In reality, both of these solution should be adopted and their inclusion would provide redudant mitigation to arguably the most likely hazard posed by Li-Ion BCM integration. As such, the condition exists during the procurement of a BCM to place a requirement upon the OEM for an integrated fire detection and suppression system. The requirement should also be flowed onto platform designers mandating a fixed fire fighting solution within the mission bay.

In addition to physical considerations such as those above, access control will also need to be considered. In order to minimise the probability of risk to personnel, incorrect maintenance, accidents or fire, the BCM module should have access limited to SQEP operator maintainers only. On HV vessels for example, HV compartments are out of bounds to non-SQEP personnel. Whilst similar practices should be implemented in this case, concurrent use of the Mission Bay will make this a challenge.

***Effector Location***

The location of the LDEW will be subject to a series of considerations and trade offs which should consider arcs, structure, cable runs and cooling. However, in reality the integration of the LDEW is limited to only a few options on most escort sized vessels – not least when placement of existing weapon systems is considered.

Feasibility studies have been progressed for the US Navy which see the LDEW integrated with a Phalanx CIWS[7]. This would carry the benefit of being able to utilise the existing CIWS structural interface and would substantially simplify LDEW integration. An open-source schematic is included for illustrative purposes in Figure 6 below. With Phalanx systems limited in their anti-surface warfare role and more optimised to anti-air warfare, this would offer an enhanced layered-defence proposition in the context of USVs.

Figure 6 – Integrated Phalanx CIWS and LDEW concept[7]

***Electrical & Power Management***

For containerised battery modules to be integrated in a timely and cost-effective manner, adoption of NATO standardised power supplies and connectors should be utilised.

A number of requirements would need to be placed on the Containerised Battery Modules to facilitate charging and discharging requirements such as the inclusions of Battery Monitoring Systems (BMS), fan and venting systems and an AC-DC interface. The Containerised Battery Module would need to contain an Uninterruptable Power Supply (UPS) unit to ensure the relevant safety critical systems remains active in the event of variations or loss in power supply. Depending on the interface with the LDEW consumer, the Containerised Battery Module provider would also need to incorporate a DC-AC power electronics cabinets within the module to facilitate power delivery. This would be required to supply loads to ancillaries as well as, potentially the HEL. This would need to be standalone and would either reside within the module itself, or in a separate dedicated cabinet or module within the mission bay. Considerations such as Ingress Protection (IP) should be considered in the specification of these cabinets if they are situated within the mission bay.

Functional integration with the Power Management System would also be required to facilitate control, monitoring and isolation alongside the LV charging circuit. Such integration would need to result in the ability to understand the charge status of the battery and manage the supply of power to the LDEW.

***Cooling***

The containerised battery module will require a cooling solution. While the module could in theory connect to the platforms chilled water system, the platform integration would be simplified if the mission module contained its own cooling system that only required power from itself. That way the Module would only consume a electrical power rather than requiring rework and expansion of the ship Chilled Water Plant and/or CW interfaces within the Mission Space.

For a containerised cooling solution to be effective the wild heat from the battery units and associated power electronics would need to be expelled through a vent or exhaust. In the case for our candidate vessel, if the Containerised Battery Module is within a Mission Bay, the heat from the containers would need to be dissipated from the compartment to prevent localised temperature rise. Typically, the mission bay would not be an air-conditioned space, nor would it sit within the citadel of the vessel. As such, simple mechanical forced ventilation to atmosphere would be required.

This places a reliance on the OEM that the requirement to integrate an integral cooling solution and flue to the container units is feasible. Based on a review of COTS Containerised Battery Modules this should not pose a challenge.

However, whilst the Containerised Battery Module cooling requirement should be met through in-container cooling, a more onerous a requirement will be the thermal management solution for the LDEW. With the vessel's Chilled Water Plants being sized for the vessels build condition, alongside a nominal in service growth margin it may be challenging to manage the cooling requirements of the LDEW by consuming the margin of the ships systems. Further containerised modules may need to be design, procured and integrated into the vessel to provide supplementary cooling for the LDEW[8].

***CMS***

The LDEW system will require integration with the ships Combat Management System (CMS). Due to the variety of CMS in operation, this will need to be a class specific integration activity. Potential opportunities to rationalise CMS integration effort can be realised if the LDEW system is integrated into the CIWS system. Sharing of data and commonality of interface would reduce the impact on the host vessel.

The level of design and rework required will depend on the level of integration the user requires. A degree of this will depend on whether the LDEW system consumes data from the CMS (as an effector), publishes data to the CMS (as a Sensor) or is in constant dialogue with the CMS. An open architecture or standardised data interfaces would aid the design and integrations of the LDEW capability. Here, further work is required to capture requirements, ascertain standards and apply extant knowledge. NATO Standard ANEP-99 does make recommendations for the Physical interface (i.e. standard Gigabit Ethernet (GbE)) to the CMS however, functional integration will require further definition..

## 8. Conclusions

This paper concludes that current mechanical vessels will remain militarily relevant despite the introduction of LDEW systems. Inherently, vessel LV systems can satisfy the requirements of LDEW systems according to previous research. As the Technology Readiness Level (TRL) of LDEW systems mature, the requirements for integration will be defined further. With this, the platform's LV system Design Authority will need to undertake a degree of electrical systems modelling to ensure that the power demands of laser systems can be satisfied by the available power on board. Whilst using ships power is feasible it attracts a number of key drawbacks which erode the value proposition of LDEW systems. These include but are not limited to; a change in LV systems CONOPS that may yield a reduction in resilience, alongside a range of negative impacts on the mechanical components that comprise the generator set.

The analysis conducted indicates that a Containerised Battery Module could service the needs of LDEW for specific case studied. Further work is required to define the ability of potentially COTS Battery Modules to facilitate the needs of LDEW. This further work will need to be influenced by a number of stakeholders including the end user, OEM's and systems integrator such that a use study, representative data, and case specific impact assessment are considered – rather than the public domain available information that forms the basis of this paper.

By segregating the requirements of providing ship service loads from the LDEW, both the LV power generation system, and the Containerised Battery Modules could satisfy their consumers without adversely compromising the other. Whilst this should not become a substitute for adequate margins management, it is hoped paper could stimulate further assessments and potentially simplify the installation process of LDEW; enabling a 'fail fast' strategy in deploying innovating weapon systems

Going forward there is a need to mature standards and requirements that relate to integration of the capability in addition to understanding how the addition of a Containerised Battery Module may impact the vessels safety and combat safety cases. As such, it could be suggested that the inclusion of adequate Size, Weight and Power and Cooling (SWAP-C) margins through the inclusion of well sized platform systems and a well placed mission bay could simplify a Fit-For-But-Not-With capability for future LDEW on mechanical vessels.

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