An Incremental Path to Achieving a Sea-Based Ballistic Missile Defense Capability for European Navies

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The continuing evolution and proliferation of ballistic missiles has been a focus in NATO for some time. While initial weapon system elements and command and control capabilities have been focused on leveraging existing and proven US weapon systems such as Patriot and the sea based Aegis Weapon System, European defense industry partners are making significant strides in establishing evolutionary paths for European air defense sensors and weapon systems. These efforts along with the recent expansion of NATO ballistic missile defense policy to territorial defense of the European continent, supported by the US Policy of the European Phased Adaptive Approach (EPAA) have created new opportunities for developing and incorporating European contributions to the collective BMD defense.

Within this context, sea-based ballistic missile defense (SBMD) contributes in a unique and significant contribution for both reaction force protection and territorial defense, given its mobility, agility, and ability to incorporate both endo-atmospheric and exo-atmospheric intercept options. The hypothesis provided herein is that sea-based missile defense can be incorporated into any surface combatant that has the inherent foundational capabilities to do so. The contribution they can perform depends on the particular nation’s ballistic missile defense (BMD) policy; that may extend from receiving a real time situational awareness picture, contribution to ballistic missile defense surveillance and tracking (BMS&T), to full engagement functionality. This paper will outline what those foundational capabilities are and will define a path for incorporating key elements in sensor, command and control (C2), weapons control, and interceptor options that can provide an incremental upgrade to select NATO member nation surface combatants. It addresses both Aegis Weapon System options and options for non-Aegis air warfare frigates such as the European Frigate and the UK Type 45 Class Surface combatant. Further, it will address potential BMD missile interceptors and integration options for Sea Based systems.

The European Phased Adaptive Approach Implications: The recent US policy announcement on the European Phased Adaptive Approach (EPAA) provides a new emphasis on NATO and European Nation contributions to the defense of Europe\(^1\). The EPAA recognized the unique contributions of sea based missile defense and the tested and proven capabilities of Aegis BMD. Phase I of the plan, leverages the first generation Aegis BMD system at sea, coupled with additional powerful shore based sensors (AN/TPY-2) and the concept of launch on remote (LOR) to field a relevant capability in 2011. Subsequent phases continue to build on the Aegis BMD capability and spiral improvements of the Standard Missile 3 interceptor. The US went on to expand the concept of phased adaptive approach in its Ballistic Missile Defense Report released in February 2010 to other regions around the world. The report recognized the need for BMD “tailored to unique deterrence and defense requirements” and “built on a solid foundation of strong cooperative relationships.”\(^2\) While the

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\(^1\) THE WHITE HOUSE, Office of the Press Secretary, September 17, 2009

\(^2\) Ballistic Missile Defense Review, February 2010
EPAA, as announced, focused on a US contribution to this important capability, the continued expansion of BMD threats across the globe creates a demand signal for NATO and coalition contributions. As such, understanding the range of contributions that European Navies can make by developing SBMD capable platforms is important to the future.

**NATO Policy in the Territorial Defense of Europe:** Recognizing the growing threat of ballistic missile technology proliferation, NATO allied leaders added missile defense as a core element of its collective defense policy at the Lisbon Ministerial Summit November 2010, and noted in the meeting declaration: “The United States European Phased Adaptive Approach is welcomed as a valuable contribution to the NATO missile defense architecture, as are possible voluntary contributions by Allies.” The Lisbon Summit reinforced this statement in its “Strategic Concept for the Defense of Security of Members of the North Atlantic Treaty Organization” by recognizing the growing proliferation of nuclear weapons and other weapons of mass destruction in describing the security environment facing the alliance. They went on to address the alliance’s intention to “develop the capability to defend our populations and territories against ballistic missile attack as a core element of our collective defense.” These intentions have lead to a healthy discussion within NATO and European industry in determining potential contributions that European nations could provide to augment the US EPAA. The inherent adaptability of robust sea based air defense systems provides a timely and realistic path to ballistic missile defense upgrades to Aegis ships in Spain and Norway. Additionally, the modern condition of non-Aegis ships in Denmark, the Netherlands, Germany, the United Kingdom, and Italy could provide ideal European national contributions by leveraging knowledge and components gained from the US Aegis BMD program.

**In going considerations:** In responding to these evolving BMD national and alliance polices, there are a couple of considerations that should be included. They are:

- **Sensor to Shooter Considerations:** In determining a set of options for sea-based missile defense contributions, a thorough understanding of the major contributory elements for successful BMD must be considered. Key elements include:
  1. Effective Multi-Mission, Multi-Platform BMD Planning to include resource management, engagement geometry, and sensor coverage.
  2. Sensor performance requirements and sensor netting to support net-centric operations.
  3. Effective time sensitive command and control.
  5. BMD interceptors and guidance.

- **Building on Proven and Tested SBMD Capabilities (Figure 1):** The ability to adapt the Aegis Weapon System (AWS) to BMD capability is well understood. The US Navy has 22 surface combatants configured for the full range of Sea-Based BMD

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3 *Lisbon Summit Declaration* issued by the Heads of State and Government participating in the meeting of the North Atlantic Council in Lisbon, 20 Nov 2010, article 37.

capability and is in the process of executing a modernization program that will upgrade all US Aegis Destroyers to SBMD capability in an open architecture, fully commercial, off-the-shelf (COTS) computing environment. Additionally, the traditional military standard Aegis BMD computer program in older baseline ships has been modified for this use. These efforts provide a range of options for international Aegis naval vessels to capture and adapt their versions of the AWS for SBMD missions, be it BMS&T or full engagement capability. Today, the Aegis BMD System is the only proven, tested, and certified sea based capability in the world. The extensive and complex systems engineering investment made by the US Government in developing these capabilities was an extension of the vision that built Aegis in the 1970’s. The experience gained in expanding its capabilities provides a critical knowledge base and several harvestable components that can be leveraged in creating a set of options to incorporate capabilities into the European Frigates and UK Type 45 surface combatant.

**Aegis BMD Success**

(Figure 1 – Aegis BMD Record of Live Fire Successes)
- **End to End Systems Engineering:** Irrespective of technology basis, SBMD integration into ship integrated weapon systems is a complex systems engineering challenge. The consummation of successful engagement against a ballistic missile, unlike air defense where aerodynamic principles can be interrupted and closing rates are less stressing, requires extreme accuracy, challenging discrimination, and critically accurate weapons guidance. Both weapon control systems and interceptors must be carefully designed and performance balanced to meet "hit to kill" criteria. These requirements demand very diligent systems engineering efforts that include not only an understanding of the dynamics of an end to end system, but extensive knowledge and experience in designing and integrating functions tailored to sensor, control, engagement, and interceptor capabilities and limitations. This systems engineering effort must also take into account the unique challenges of handling engagements in and out of the atmosphere. In short, it is not good enough to just be a good air defense systems engineer. It takes space environment, hit to kill, and ballistic flight knowledge to adapt any robust air defense capability to SBMD. Aegis BMD has been successful because of the robust US Government/US Industry team that contains the extensive experience and knowledge required.

- **Affordability and implementation:** Adding capabilities to existing platforms must be accomplished with sensitivity toward efficient implementation and sensitive to cost or affordability. Most costly is requiring changes to interceptors outside of current programs of record. Systems engineering efforts should avoid changing missile programs as a priority. System configurations that are fielded should be leveraged to maximum extent possible. Incremental improvements to sensors, command and decision, and weapons control must be done in a way to minimize impacts where practical.

**Foundational Capabilities and European Development Efforts that can enable a Sea-Based Missile Defense Capability:** Application of the above considerations requires an understanding of the foundational capabilities needed to support an SBMD upgrade. First, BMD Planning tools are needed to ensure the sensors are configured correctly to detect and track the threat and provide sufficient data to calculate an engagement. Planning must consider the area to be defended, the threat launch areas to be denied, and define an area in which the ship can operate effectively. Then the sensors must be capable of detecting and tracking multiple objects at long range and discriminating the lethal object. The decision to have an engagement capability must consider the match between the sensor and the potential interceptor missile. Some organic sensor considerations are:

1. **Aegis BMD** - Aegis BMD makes use of the SPY-1 S-band radar which has proven to be ideal for a multi-mission ship. The legacy system provides an excellent air defense, ASW, and strike platform and has now been modified to conduct BMD surveillance and engagement operations.

2. **SAMPSON Radar for UK TYPE 45 Frigate** - The UK has the SAMPSON S-Band radar and the S1850M L-Band radar. It remains to be seen how these radars will be engineered into the system with the PAAMS for BMD. The Type 45 could be
deployed as a surveillance asset to cue Aegis and other BMD shooters in the European Phased Adaptive Approach (EPAA).

3. **SMART L Radar Option for European Frigates (NL/DK/GR)** - These countries have frigates with the SMART L L-Band and the APAR X-Band radar. One can surmise that if the countries that own these platforms decide to have a BMD mission they will conduct the proper systems engineering to ensure that these systems will be integrated with the command and control and interceptor missiles to address the particular ballistic missile threats which concern them.

In addition, the maturation of the NATO BMD System will include the addition of more powerful and strategically positioned radar and infrared sensors netted together in a time sensitive architecture. This sensor grid will evolve to provide fire control quality unambiguous BMD track data that can be coupled with the remote weapon system concepts “launch on remote (LOR)” and “engage on remote (EOR).” The LOR concept can be used to enhance organic fire control systems in an affordable way, and EOR could provide the sensor support required for any surface combatant that has the launcher infrastructure and weapons control that can support a BMD capable interceptor.

**SBMD Command and Control:** The command and control system processing must be capable of supporting real-time decision making. In some cases, decisions must be preplanned and automatic based on pre-set rules. Integration of missile defense capability into an existing ship with various defense capabilities requires careful systems engineering to ensure that multiple mission capability is not lost. In some cases it may be necessary to have a BMD mode where there is limited or no capability to conduct other missions.

CDS Considerations are:

1. The Aegis Weapon System (AWS) is a radar and a missile system integrated with its command and control system, capable of simultaneous operation defending against advanced air, surface, and subsurface threats, while automatically implementing defenses to protect the fleet against aircraft and missiles. The system is capable of countering all existing and emerging threats to a naval battle group, as well as striking inland targets. Additionally, it provides regional and national defense capabilities against short and medium range ballistic missiles. The Aegis BMD Weapon System seamlessly integrates the SPY-1 radar, the MK 41 Vertical Launching System, the SM-3 and SM-2 BLK IV missiles and the weapon system’s command and control system. The Aegis BMD Weapon System also integrates with the BMDS, receiving cues from and providing cueing information to other BMDS elements. The SPY-1 radar, augmented by the Aegis open architecture BSP signal processor, provides an advanced discrimination capability to defeat more complex ballistic missile threats.

2. For ships that are not originally built to perform the BMD mission, it will be necessary to enable the ships command and control system to perform this mission. An easy and affordable way to do this is by augmenting the ships original command and control system with a BMD-enabled system, such as BMD-Flex. This augmentation means adding a low number of extra workstations (usually 1-3) with BMD-Flex software to the ships configuration and then building a dedicated interface between the BMD-Flex and original C2 system that enables the transfer of relevant data between the two systems. In this way, the operators performing the BMD mission will use the BMD-Flex system,
Engagement Capability: Developing an effective set of engagement options is the most challenging of the contributions an SBMD ship can provide. It requires a robust BMS&T sensor, effective command and control, capable real-time data exchange with other contributing elements of a BMD system and the ability to control a high energy interceptor to a “hit to kill” engagement. Key foundational capabilities include:

1. **Aegis BMD Fire Control Module** – In Aegis, the BMD fire control loop is a closed system with careful engineering of each element to continually reduce tracking and guidance errors and support a hit to kill intercept. In the case of launching or engaging on remote data (BMD tracks from another BMD sensor) the engagement loop is still closed, but the remote sensors must meet a specified quality of service with their track data to ensure successful closure. Adopting the tested, fielded, and operationally certified Aegis BMD fire control loop is lowest risk, most timely, and likely most affordable option for adding SBMD engagement capability into both Aegis and non-Aegis air defense ships. It is backed by over 30 years of US Navy investment supported by a brain trust of US Government and Industry engineering talent to include intimate knowledge in exo-atmospheric weapons control and kill vehicle dynamics required for effective RMD defense.

2. **Vertical Launching System Compatibility** – The MK 41 Vertical Launch Systems is made up of modules which contain cells that can hold eight interceptor missiles each.
The missile launch system must be considered part of the trade space when engineering BMD into a ship system since there is a decision as to how to load out the launcher system with BMD missile variants or other tactical missiles for air defense and strike. It is advantageous to follow an any missile, any cell approach to ensure flexibility.

3. **Missile Communications** – In BMD, missile communications is a critical component in fire control. The guidance laws incorporated within the Aegis Weapon System are key to its success in BMD. The current SM2 and SM3 receive their guidance instructions via an S-Band uplink within the SPY-1 radar control. The missiles have an S-band receiver to support the communication. Providing missile communication to European Aegis ships requires no changes to the system or the missile. If these interceptors require adaptation to non-Aegis ships, there are two paths that could be adopted.
   a) Provide an adjunct S-Band uplink system, similar to those used in the US New Threat Upgrade (NTU) program in the 1990's. This approach is essential to retain the low risk tested pedigree of the Aegis Fire Control loop, especially for SM3 exo-atmospheric interceptor.
   b) Upgrade the APAR X-Band for BMD endo-atmospheric missile communications.

**Exo- and Endo-Atmospheric Interceptor Considerations** - The decision to have an engagement capability must consider the match between the sensor and the potential interceptor missile. For a point defense, an endo-atmospheric capable missile can provide defense against shorter range threats. For defense of a larger regional area, an exo-atmospheric missile will be needed. Using the exo-capability, ships may be forward deployed close to the threat launch areas or operate in the terminal area. Whether the interceptor missile has hit-to-kill, hit-to-kill augmented, or fragmentation warhead must also be considered. Missile options:

1. **Standard Missile 3 (Exo-atmospheric)** – This missile is the backbone of the Aegis BMD interceptor capability and is has a proven performance record in upper tier BMD defense. It is currently the only viable option in the case of upper tier support to the EPAA.
2. **ASTER-30 (Endo-Atmospheric)** is in testing for AAW and short range BMD capability. It is already in use in several European Navies, most notably for BMD with the UK Type 45 Destroyer. It is expected to be followed by the ASTER 30 NT and ASTER BLK I with increasing capabilities
3. **Standard Missile SBT Variant** – The US Missile Defense Agency and US Navy are presently developing the next generation sea based terminal interceptor that may be available to the international community in next decade.

The discussion to this point has been to explore the foundational capabilities required in order to consider a surface combatant for SBMD. The next question is how any of these options can be integrated into an existing weapon system and what options are there to do so. The answer lies in two important information technology enablers; Open Architecture and the application via an Open Business Model.

1. **Open Architecture**: Key to the upgrade of most Aegis and the Non-Aegis air warfare surface combatants to SBMD is the emergence of open architecture - based
technologies and the ascendance of the open business model. These two key realities allow for modular upgrading of command and direction systems (CDS) by integration of the software components required for effective situational awareness and command and control; the upgrade of radar systems with software based signal processing; the component harvesting of the Aegis BMD weapons control system (WCS OA); and the integration with the MK 41 Vertical Launching System, all without affecting the interceptor design. Key tenets of open architecture that allow for these options are: open and published interface standards, standard COTS computing environments, modular design of software, and non-reliance on customized hardware.

2. Application of the Open Business Model (Figure 3): The ability to harvest or develop specific software components that can provide the BMD capability to an existing ship CDS system is key to providing an affordable path to upgrading European ships for BMD. The business model that supports this approach is the open business model. For purposes of clarity, three broad use cases are applied.

- **Use Case 1** is applied to a situation where no previous system exists. It allows the provider to establish a modern OA compliant architecture that is capable of accepting components from any source. It is not used in this discussion as in service systems are being addressed.
- **Use Case 2** recognizes there is an existing command and direction system (CDS), but it was developed for OA technical conditions were available. This use case incorporates an adjunct relationship with a modern OA compliant SOA to incorporate modern modular software components for BMD augmentation.
- **Use Case 3** recognizes that there are CDS fielded that already conform to OA. It allows the incorporation of BMD components directly into its architecture.
3. Use cases 2 and 3 allow European Navies the ability to build on their investments in robust air defense ships with specific targeted upgrades to support the level of SBMD contribution their national policies demand. As an example, the BMD-Flex capability bundle represents many of the key elements that an air defense CDS will need for augmentation. These capabilities can be incorporated in two different ways depending on the technology epic in which the existing CDS was developed. If it conforms to modern open architecture standards, the specific components in BMD-Flex can be integrated as contributing elements. If the CDS is a traditional order monolithic software design, a modern service oriented open architecture framework can be inserted as an adjunct and an interface built to use the existing CDS as a service for SBMD capability.

(Figure 4) An Incremental Approach European SBMD

A Practical Application of Sea Based Missile Defense (SBMD) Capability in a non-Aegis Surface Combatant (Figures 4,5,&6): The European Air Defense Command Frigate developed by the Netherlands, Denmark, and Germany represents a good example of the application of the considerations supplied in this paper to provide SBMD capability to a non-Aegis ship. This example leverages the ongoing BMD sensor development efforts with the Thales SMART-L Radar to provide the BMS&T capability for these ships. The key capability integration to build on this sensor to provide engagement capability is as follows:

1. Augment the ship’s CDS with the critical command and control and situational awareness elements needed for effective BMD planning and execution. The BMD-Flex capability bundle can provide these capabilities in either a Case 2 or Case 3
approach depending on the CDS pedigree. Key components include Link 16 space tracking and special points, shared early warning injection, rule-based decision aids, robust Joint Range Extension Protocol (JREAP-C) connectivity, threat evaluation, and engagement management functions.

2. Provide a capable weapons control capability via component-designed Weapons Control (OA) harvested from Aegis BMD. This capability provides the control requirements for the existing BMD sea-based interceptors, SBT, and SM3.

3. Develop the additional interface requirements and upgrades for the MK41 VLS systems these ships have incorporated in their air defense systems.

4. Develop an S Band missile uplink capability to support command guidance of the missile to target.

Consider the following:

(Figure 5) European Frigate – Practical Example

1. Sensor Capabilities: There are two options considered in this example, organic and the ability to leverage the BMD sensor grid through EOR. The organic sensor would be the BMD upgrade of the SMART-L/APAR radar suite. These Sensors must be capable of detecting and tracking targets at long range and very high altitude and speed and meet the bandwidth demands required to detect and resolve closely space objects, and discriminate the lethal object. These Sensors must have the resources available to provide track data on multiple threats to the engagement function at the data rate required. The Dutch Navy funded a prototype demonstration of the BM surveillance and tracking (BMS&T) capability out at the Pacific Missile Range Facility in
The test validated the technical ability of the radar supporting an ongoing program to complete the design and field the upgrade. The BMDS Sensor Grid option assumes that NATO continues to improve its BMD land and space based sensor capabilities to meet the same criteria identified for the organic sensor. The EOR capability would be harvested from the EPAA evolution to EOR in Phase 3.

2. **BMD Command and Control**: This example embraces a bundle of open architecture compliant BMDC2 capabilities built in cooperation with Terma AS Denmark called BMD-Flex. These capabilities are provided in a real-time OA compliant service oriented architecture capable of accepting modern modular components under the OpenFlex™ concept in cooperation with Lockheed Martin. BMD-Flex has been extensively tested for functional performance and interoperability at NATO and US Coalition Warfare Interoperability Demonstration/Exercise over the past 5 years. Additionally BMD-Flex successfully performed during the US Flight Test Maritime 15 (FTM-15) where the EPAA Phase 1 architecture and LOR concepts were proven in a realistic BMD environment. The specific capabilities include:
   a) An IAMD Planner for deliberate multi-platform plan development
   b) Coalition shared early warning injection
   c) Automated design processes for BMD battle space management
   d) Threat evaluation and engagement coordination functions
   e) Mission monitoring and alerts

3. **Aegis BMD Fire Control Module**: The weapons control (or engagement) function must receive track data from the sensor, form its own track, perform engageability calculations, select, schedule and launch an interceptor and provide target information and/or guidance for the interceptor. The weapons control function may be required to schedule an illuminator radar. Subsequent to the end game, the weapon control function may also conduct kill or hit assessment. The Aegis BMD Weapon System has an OA compliant weapons control system (WCS) that contains the critical guidance processes needed to provide missile initialization and command guidance of SM3 and SM2 BLK IV. These control requirements have been painstakingly developed and tested since the program inception. Harvesting them in a discrete protected component provides a risk mitigated affordable way for upgrading any command and direction system that requires BMD weapons control.

4. **Vertical Launching System MK-41**: The vertical launch system (VLS) must be considered in the design process since ballistic missile interceptors due to their longer range and high $V_{BO}$ requirements generate more stringent requirements for heat transfer in the launcher and blast effects on the ship structure. The VLS load out must also be considered since there are multiple missile types for AAW, self defense and strike. Ideally, the design should accommodate any missile in any cell for maximum flexibility. The MK-41 is used in the Aegis BMD system and as such has a set of well understood ordnance alterations that can be easily applied to the European Frigate MK41 launchers. Additionally, there is a well understood interface and compatibility with the Aegis BMD weapons control system used in the “Black Box Fire Control” design.

5. **Interceptors**: There are two missiles considered relevant for this example. The exo-atmospheric interceptor is the SM3BLK IB. This missile would be the primary
contributor in the defense of Europe and is compatible with the Aegis WCS and MK-41 VLS. It would be incorporated to support the upper tier engagement requirement primarily supported by EOR.

6. **Missile Uplink/Down Link:** This example could incorporate the options previously discussed; augmenting the sensor suite with an S-band uplink/downlink for SM3 missile communication and X-band for lower tier interceptors.

(Figure 6) European Frigate – Closing the Fire Control Loop

These sea-based platforms will be important contributors as the US program works through the phases to include the addition of THAAD, and improved SM3 and Next Generation Aegis Missile (SM3BLKIIIB) interceptors. As important, the continued expansion of the BMD sensor grid to support the “launch on and engage on remote” capabilities these ships may provide will improve overall BMD defense performance for Europe and eventually the United States homeland. Finally, sea-based assets are generally the first to arrive in regions around the world to support coalition and NATO rapid deployment force employment in crisis. Because of their mobile nature and unencumbered sovereignty character, these assets provide the European Navies and NATO with significant and robust capabilities, be it situational awareness, long range surveillance and tracking capability, or full engagement employment.

**Conclusion:** Sea based missile defense can be incorporated into any surface combatant that has the foundational capabilities to do so. The contribution they can perform depends on the national ballistic missile defense (BMD) policy of the nation for which they belong; from providing a real time situational awareness picture contribution to the ballistic missile defense...
surveillance and tracking (BMS&T) capabilities to full engagement functionality. Through application of the Open Business Model, specific software components that can provide the BMD capability to an existing ship command and decision system are key to providing an affordable path to upgrading European ships for BMD. This approach will facilitate European Navies’ ability to build on their investments in robust air defense ships, radars, and missiles with specific targeted upgrades to their command and decision systems to support the level of SBMD contribution their national policies demand.