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THESIS

FEASIBILITY OF DEVELOPING A SURROGATE MISSILE SYSTEM FOR THE PURPOSE OF COMBAT SYSTEMS TESTING, EVALUATION, AND WATCHSTANDER PROFICIENCY

by

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June 2014

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Aegis readiness is an increasing concern as ships age, Navy budgets shrink, and potential adversaries make strides toward combat power parity in diverse regions around the world. Keys to combat effectiveness are materiel readiness and crew proficiency. Live fire missile exercises are a proven way to gauge the former while contributing to the latter, but the use of combat missiles for this purpose is both expensive and depletes the inventory on hand should conflict break out.

This study explores the feasibility, required functionality, and costs involved in bringing a reusable missile system to the fleet from a systems engineering perspective. This system would notionally allow a greater number of live fire exercises while simultaneously reducing the cost required to do so. By recognizing a fleet need, bringing in stakeholders who stand to benefit from such a concept, and applying analysis to a high-level systems structure, recommendations and topics for further study were generated. These aim to further advance the concept of a recoverable test missile for use in proficiency firing events.

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Submitted in partial fulfillment of the
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ABSTRACT

Aegis readiness is an increasing concern as ships age, Navy budgets shrink, and potential adversaries make strides toward combat power parity in diverse regions around the world. Keys to combat effectiveness are materiel readiness and crew proficiency. Live fire missile exercises are a proven way to gauge the former while contributing to the latter, but the use of combat missiles for this purpose is both expensive and depletes the inventory on hand should conflict break out.

This study explores the feasibility, required functionality, and costs involved in bringing a reusable missile system to the fleet from a systems engineering perspective. This system would notionally allow a greater number of live fire exercises while simultaneously reducing the cost required to do so. By recognizing a fleet need, bringing in stakeholders who stand to benefit from such a concept and applying analysis to a high-level systems structure, recommendations and topics for further study were generated. These aim to further advance the concept of a recoverable test missile for use in proficiency firing events.

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LIST OF ACRONYMS AND ABBREVIATIONS

ASCM	anti-ship cruise missile
AMDR	air and missile defense radar
AWS	Aegis weapons system
BIT	built-in test
BMD	ballistic missile defense
CBA	capabilities-based assessment
COI	critical operational issue(s)
CONOPS	concept of operations
CSES	canister safe-enable switch
CWI	continuous-wave illumination
DRM	design reference mission
DT&E	developmental test and evaluation
DTT	dynamic test target
EMI	electro-magnetic interference
FCS	fire control system
FMS	foreign military sales
ESSM	Evolved Sea Sparrow Missile (RIM-162)
GMLS	guided missile launch system
GPS	Global Positioning System
HERO	hazards of electromagnetic radiation to ordinance
JCIDS	Joint Capabilities Integration and Development System
LSF	low /slow flyer
MOBI	man overboard indicator
MOE	measure(s) of effectiveness
MOP	measure(s) of performance
NEW	net explosive weight
NSSM	NATO Sea Sparrow Missile (RIM-7)
ORTS	Operational Readiness Test System
RHIB	rigid hull inflatable boat
SAR	search and rescue

SM	Standard Missile (RIM-66/174A)
SRM	solid rocket motor
STM	Surrogate Test Missile
STMS	Surrogate Test Missile System
TWT	travelling wave tube
UAV	unmanned aerial vehicle
VLS	Vertical Launch System
WCS	Weapons Control System
WCT	warhead compatible telemeter

EXECUTIVE SUMMARY

As Aegis surface combatants age, maintaining both materiel readiness and personnel proficiency is a top priority. This thesis proposes a novel solution that would allow fleet live-firing exercises to be increased, while simultaneously reducing the cost of doing so. This solution, the Surrogate Test Missile (STM), was selected from multiple alternatives to address the problem of increasing readiness. A systems engineering process was tailored to the problem, under the constraints of the selected alternative's conceptual nature, and was applied throughout the thesis effort. This process model draws on the Joint Capabilities Integration and Development System process as well, and allows for integration of the work done here with future work on the same subject.

To frame the problem, the alternatives were discussed with various stakeholders across the country, both within the Navy and within industry and academia. The input gathered from the stakeholders was refined into effective needs. Analysis of the stakeholder effective needs was then applied to a refinement of the problem statement. The scope of the report was then defined, based on both stakeholder needs and limitations and constraints imposed by the timeline and resources available. Stakeholder needs were also translated into system needs. The effective needs determined to be key drivers for STM development were safety, cost effectiveness, and the ability to verify readiness.

To begin to define the required functionality of the STM a series of concepts of operations (CONOPS) were developed. These define the intended usage of the STM, and include considerations for different functional solutions. The initial CONOPS were then expanded through the use of both scenarios and vignettes to examine desired responses, further identify required functionality, and expand upon the initial CONOPS. These were all then distilled into a design reference mission (DRM), which serves as a baseline for potential future test and evaluation. The DRM, as described, lays out the expected conditions and actions of the firing unit for each phase of a STM test event.

A partial functional decomposition of the STM was next conducted. This involved breaking down the initial listing of required functions and providing detailed definitions

of each desired primary, secondary, or tertiary functionality. Following the decomposition, novel functions included in the conceptual round were examined in detail to begin the process of allocating form to function. Additionally, a discussion on canister selection alternatives was briefly detailed to illustrate the possible choices. The results of the decomposition show that the functionality required for the concept has largely already been developed, and that the work required to integrate the remaining functions is limited in scope.

The functional decomposition and CONOPS were then used as a baseline for the identification of Critical Operational Issues (COIs). These issues were determined to be Survivability, Safety, Interoperability, Maintainability, and Effectiveness. Each was examined in detail to determine ways both to define and measure the desired parameters of the concept. Each was broken down further into measures of effectiveness (MOE) and measures of performance (MOP). MOEs are criteria for measuring overall system effectiveness, while MOPs are used to evaluate more specific criteria relating to the performance of systems or subsystems. These serve to inform future design decisions and preliminary test and evaluation planning.

Drawing from both the COIs identified and the functional decomposition, high-level system requirements were derived. These system level requirements, along with the MOEs and MOPs help to define the trade space utilized during detailed design and component selection. Requirements requiring specific values were assigned, instead, placeholder values. This allows future work to be conducted within the framework of the requirements that were generated without being biased or otherwise constrained by hypothetical values. Qualitative requirements were also generated based upon the novel functions previously identified.

The cost of the Surrogate Test Missile concept was next estimated via analogy using the development of the Evolved Sea Sparrow Missile as the analogous system. By assuming that a similar consortium would be leveraged to offset R&D and acquisition costs, and making further assumptions regarding the cost of canisters and overhaul, it was demonstrated that the Program Acquisition Unit Cost of the STM would be a fraction of that of the ESSM, anywhere from roughly one-third to one-eighth the cost. The precise fraction would depend primarily on the learning curve experienced for the production units and the total quantity acquired.

The feasibility of the preliminary STM concept, and the cost estimates pointing toward the realization of considerable cost savings result in the emphatic recommendation that this concept continue forward toward development. This study provides an analytic framework from which detailed design, analysis of alternatives, and developmental test and evaluation can be conducted. Further study should focus on the aforementioned design, as well as on a more detailed analogy or parametric cost estimation.

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I. BACKGROUND

A. FUTURE READINESS ISSUES

The backbones of the surface combatant fleet today and into the foreseeable future are its Aegis-equipped cruisers and destroyers. In recent years, the readiness of these systems has undergone a very public decline, as evidenced by increases in the number of Casualty Reports and stark increases in INSURV failures. VADM (Retired) Balisle's panel distills these facts in the Surface Force Readiness report of 2010, which noted a culture in which operating degraded gear is considered acceptable.[1] Since then, efforts have been made to counter these trends, including increasing manning levels and improving the "fit" of personnel, and increasing the frequency of live-fire test events, which had been curtailed in the mid-2000s in favor of more simulated (synthetic) training. This resulted in the Aegis wholeness project, and after four years of effort, the Navy has declared that materiel issues are no longer a concern for Aegis units.[2] This is promising news, but the fact remains that the defense budget remains uncertain, and increasing fiscal pressures may again impact maintenance and readiness in the coming years.

This potential is made more serious by the planned obsolescence of the SM-2 family of surface-to-air missiles, currently scheduled for the mid-2030s timeframe[3]. The replacement area defense missile, the SM-6, has a current average per-unit cost of $4.4 million (in FY14 dollars), making this missile round simply too costly for use in testing of the combat systems suite or for training, even as this cost is reduced through increased volume purchases later in its life cycle.[4] The RIM-162 Evolved Sea Sparrow Round has simultaneously increased in price per round, with 2014 acquisition figures

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[1] Phillip Balisle, *Fleet Review Panel of Surface Force Readiness* (Annapolis, MD: Galrahn, 2010), 43, http://www.scribd.com/doc/43245136/Balisle-Report-on-FRP-of-Surface-Force-Readiness.

[2] Sam Lagrone, "The Next Act for Aegis." *USNI News*, May 7, 2014. http://news.usni.org/2014/05/07/next-act-aegis

[3] Sidney Hodgson, e-mail message to author, November 25, 2013.

[4] Department of Defense (DOD), *Selected Acquisition Report: Standard Missile-6*. (Arlington, VA: Defense Acquisition Management Information Retrieval, May 21, 2013), 20. (FY04 $ converted to FY14 using 2014 JIC calculator 1507 cost element.)

approaching $1 million dollars (FY 2014) per round.[5] These increases in price will likely have the effect of reducing the frequency of fleet live-fire events, which could, in turn, increase the risk associated with all future test firings as well as combat firings.

Simultaneous with increasing readiness concerns, additional missions and threats have emerged. The continued proliferation of supersonic sea-skimming cruise missiles such as the Novatar Klub series, the introduction of Anti-Ship Ballistic Missiles, and the Ballistic Missile Defense (BMD) mission all serve to raise the stakes for deployed naval forces. These new threats represent a direct challenge to the area defense capabilities of Aegis, and as a result, a combat systems failure no longer imperils only the lives of those onboard the firing unit. Increased proficiency, an emphasis on more immersive training, and novel ways of assessing readiness are all required to meet the challenges posed by these current and future threats.

B. INITIAL ANALYSIS OF ALTERNATIVES

1. Comparison of Available Alternatives

To achieve the goal of increasing the readiness of the combat systems suites of fleet units, there are a number of viable options. The first, which has been pursued over the past decade, is the use of synthetic firing events to verify proper operation. While this provides the lowest cost of all methods, it is inherently limited in that the firing train is not fully utilized. Further, measurements of RF are conducted at dummy loads, which may or may not correlate to what would actually be leaving the antenna feedhorn and arriving at the missile or target. For these reasons, while synthetic firing events provide excellent value, they are at best incomplete, and at worst misleading.

The second option would be to conduct fleet proficiency firing events utilizing the SM-2 inventory. As these rounds age, their military utility decreases, and thus disposal through a firing event is preferred. The disadvantage to this approach is that the inventory, while large, represents the sum total of the Navy’s area air defense arsenal until SM-6 production has built up a large enough inventory. SM-2 production ceased in

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[5] U.S. Department of the Navy, *FY 2014 President’s Budget*; *Justification Book Volume 1; Weapons Procurement, Navy*. (Washington, DC: DON, April 2013), 142.

2011, and no further rounds will be procured as production shifts to the SM-3 and SM-6 variants of the missile.[6] Furthermore, the firing of a SM-2 requires clearing a very large firing range—over 80 nautical miles downrange and 15 degrees to either side of the firing bearing. This necessitates the use of non-organic (not carried on the ship itself) patrol aircraft for range clearance duties, and makes conducting these firing events difficult in many oceanic areas due to surface and air traffic.

A third option would be to utilize the Evolved Sea Sparrow Missile (ESSM) in place of the SM for fleet proficiency firing. These missiles are relatively cheap compared to the SM-6, with a per-round cost of just less than $1 million, and warhead-compatible telemeter (WCT) devices adding approximately $74,000.[7] Furthermore, the limited range of the ESSM compared to the SM poses less of a constraint to firing location and required range clearance assets.

A fourth option, the one to be investigated in this thesis, is to develop and field a recoverable surrogate test missile. This missile would simulate the functionality of potentially multiple missile types, communicating with the firing unit’s combat systems suite accordingly. Enhanced data recording and retrieval would streamline post-firing data collection and analysis. It would share the ESSM’s limited range, and possess better inherent safety due to its lack of warhead. Following each firing event, the airframe and electronics, along with its canister if fired from the VLS, would be reused after overhaul. The cost of a firing event would thus be reduced to the cost of a new solid rocket motor, overhaul of the missile and canister, and transportation.

Another related option would be to develop and field a non-recoverable surrogate test missile. Following a firing event, there would be no need to recover the airframe or electronics. Cost savings would result from not needing to recover the airframe after each mission, transport it to a suitable facility for overhaul, and from the reduced ruggedness required for a single-launch platform.

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[6] Ibid., 74.

[7] Ibid., 142.

C. SYSTEMS ENGINEERING PROCESS

1. Selected Process Model

Given the range of available models and the scope of this report, the “waterfall” process model was selected, and tailored to provide the best fit to the anticipated scope of this report. This model, first introduced in 1970, usually contains between five and eight steps or phases. These are typically sequential, sometimes with a continuous feedback loop informing each step[8]. This basic model was taken, and tailored specifically to the goals of this thesis. It will be used as a guide throughout the research and writing, and informs the approach taken in developing and fleshing out the subject concept. Its sequential steps thus become chapters or sub-chapters of the thesis report, and each feeds into the next. The layout of the tailored process model in Figure 1 is intentionally a rough approximation of the layout of this thesis.

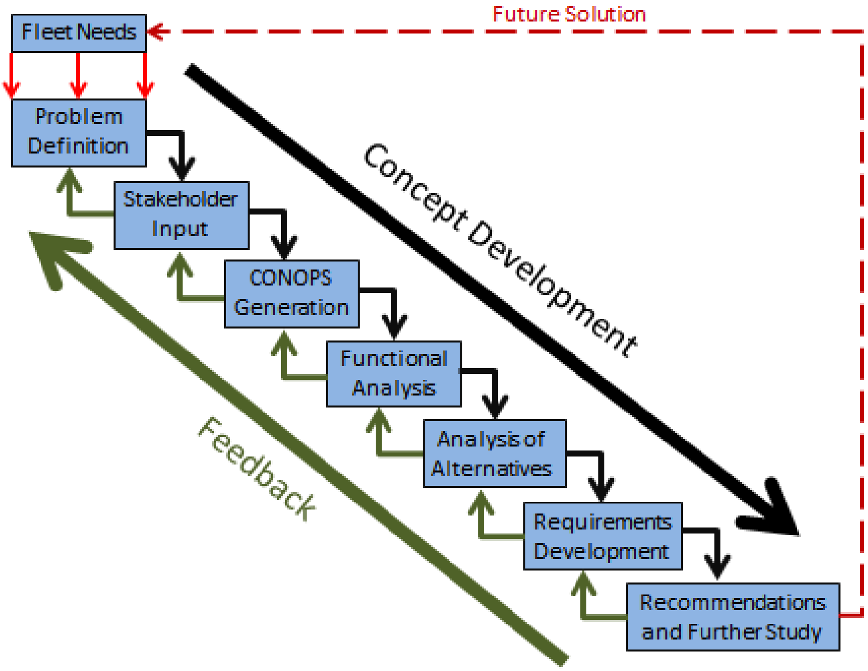

Figure 1. Tailored Process Model.

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[8] Benjamin Blanchard and Wolter Fabrycky. *Systems Engineering and Analysis 5th edition.* (Upper Saddle River, NJ: Prentice Hall, 2011), 36.

The tailored process model, depicted in Figure 1, is fed by the needs of the fleet, depicted in red. The black arrows depict sequential process steps, while the green arrows depict the iterative feedback received through further research and stakeholder interaction. The feedback is not necessarily iterative, but rather flows back up the process to any previous step. The desired outputs of this project are recommendations and topics identified for further study, with a potential future solution identified to meet the needs of the fleet.

This model serves as a roadmap to be used to guide the analysis and research into the chosen concept. As this concept is further developed throughout the report, each step will be addressed sequentially, with feedback being applied to earlier work or explored further via stakeholder interactions. While each step is not necessarily its own chapter, the thesis was laid out in such a way that it would follow along with the process model coherently.

2. Joint Capabilities Integration and Development System Process Integration

The majority of the topics addressed by this thesis fall under the Capabilities Based Assessment (CBA) portion of the Joint Capabilities Integration and Development System (JCIDS). This assessment is conducted "to assess capability requirements and associated capability gaps and risks.[9]. In this case, the identified capability gap is the lack of a cost-effective means to provide live-fire training and readiness assessment to AEGIS-equipped ships. The assessment is based, in part, on high-level strategy and guidance such as that provided in the *Quadrennial Defense Review* (QDR)[10]. The 2010 QDR states that "as we apply resources, we will prioritize readiness and capability over capacity" and "the United States seeks to develop additional opportunities for joint and combined training in the Western Pacific that respond to the need for constant readiness

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[9] Chairman of the Joint Chiefs of Staff, CJCSINST 3170.01H; *Joint Capabilities Integration and Development System.* (10 January 2012), Enclosure A, A-1

[10] Ibid., A-2

of U.S. forces to carry out joint operations."[11] This concept fulfills the identified needs of prioritized readiness and provides additional opportunities for training in support of that readiness.

Specifically, this thesis addresses a specific idea for a material approach. The newest versions of the CJCSI instruction no longer break down the CBA into its component parts, but referring to previous versions (specifically CJCSI 3170.01F) helps place this thesis into a specific context. As shown in Figure 2, the process leading to an Initial Capabilities Document requires both a functional needs analysis as well as a functional solution analysis of specific ideas for a material approach to the identified need/needs. For the purpose of this thesis, Section B of the 3170.01F, describing different ideas for material and non-material approaches to the need of maintaining and enhancing readiness would be an example of a functional needs analysis[12]. The bulk of this thesis will be spent examining the selected material approach alternative in depth and is an example of a functional solution analysis.

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[11] Department of Defense, *2010 Quadrennial Defense Review Report.* (Washington, DC: DOD, February, 2010), 66, 104

[12] Chairman of the Joint Chiefs of Staff, CJCSINST 3170.01F, *Joint Capabilities Integration and Development System*, (May 1, 2007), Enclosure B, B-1 - B-4

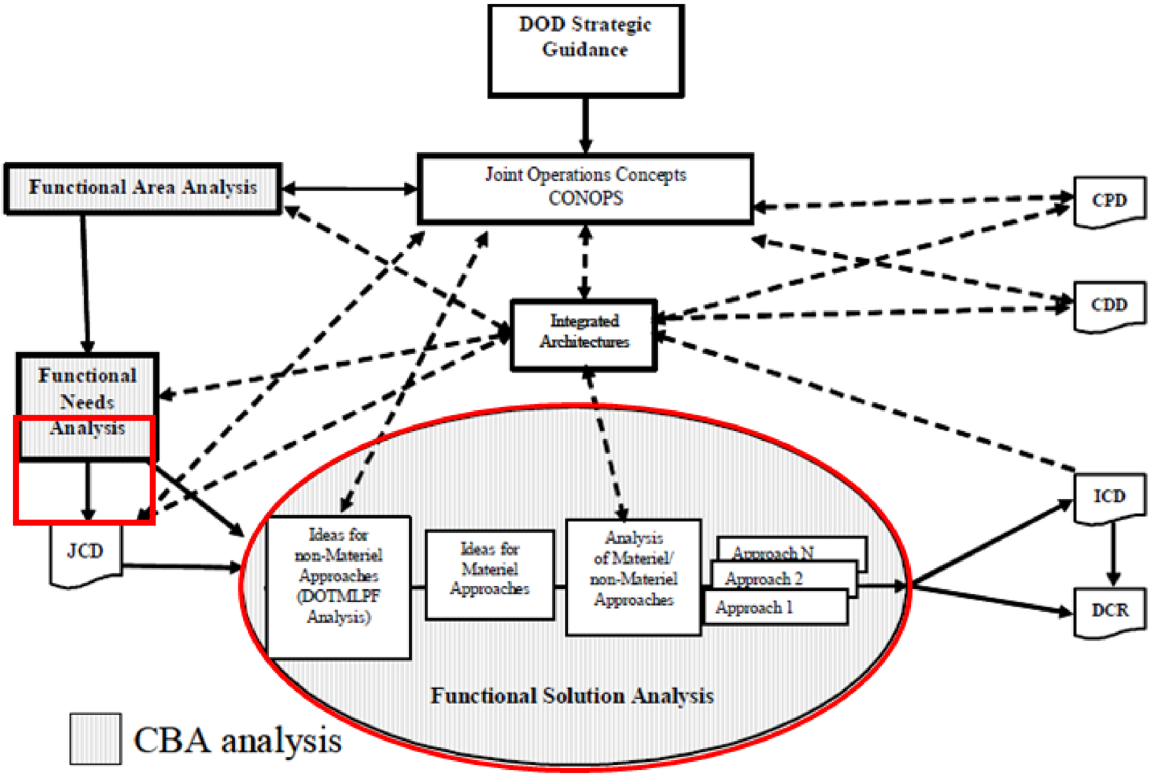

Figure 2. Focus of the Capabilities Based Assessment Process within JCIDS.[13]

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[13] "JCIDS Process; Functional Solutions Analysis," AcqNotes, accessed February 12, 2014, http://www.acqnotes.com/Acquisitions/Functional%20Solutions%20Analysis%20.html

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II. STAKEHOLDER ANALYSIS, PROBLEM STATEMENT AND SCOPE

A. STAKEHOLDER IDENTIFICATION

1. Project Stakeholders

The primary stakeholder is the project sponsor, PEO IWS 1 (Aegis Fleet Readiness). Other stakeholders include, in no particular order: Aegis Training and Readiness Center; Naval Surface Warfare Center (Dahlgren, Corona, and Port Hueneme); Surface Combat Systems Center Wallops Island; Naval Surface Forces; Commander, Operational Test and Evaluation Force; PEO IWS 3 (Standard Missile and Evolved Sea Sparrow Missile); PEO IWS 4 (FMS); OPNAV N86 (Surface Warfare); OPNAV N865 (BMD Afloat); Combatant and Fleet Commanders; and fleet users. Additionally, a number of civilian contractors have been identified who would likely be stakeholders should this project be pursued beyond the academic level. These include, but are by no means limited to: ATK Aerospace Group, producers of navalized solid-rocket motors; BAE Systems, Land & Armaments Division, produces and refurbishes VLS canisters; and Raytheon Missile Systems, producers of airframes and guidance components.

A geographic representation of stakeholder distribution is provided in Figure 3:

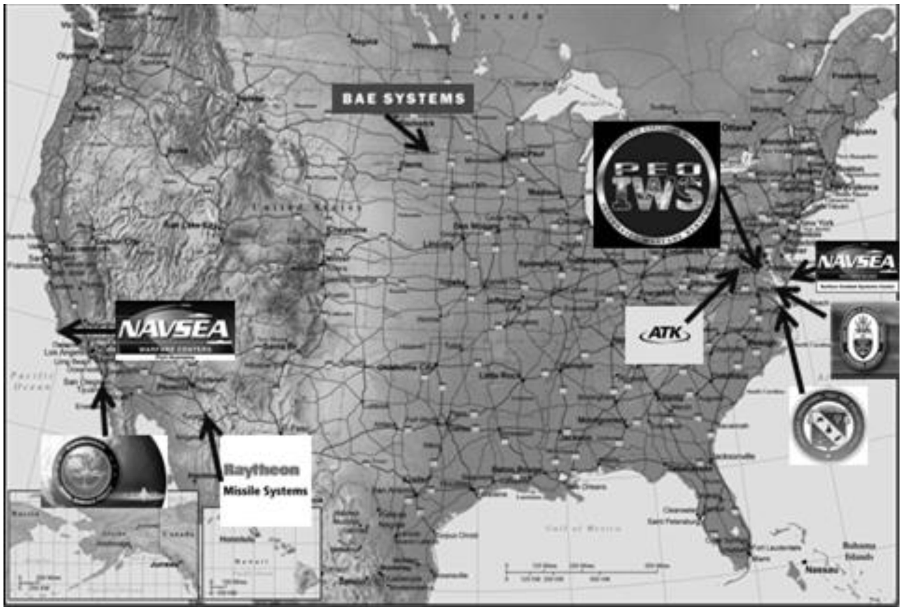

Figure 3. Naval Enterprise Stakeholders for Surrogate Test Missile Concept.[14]

B. STAKEHOLDER ANALYSIS

Limited sponsor engagement was conducted prior to commencement of thesis work. This included an informal meeting with CAPT Thomas Druggan, head of PEO IWS 1, immediately following an on-campus briefing. Fredrick Rischmiller, Aegis In-Service principal/assistant project manager for PEO IWS 1, was engaged shortly thereafter, and arrangements were made for travel to Washington, DC, to meet with individuals in the sponsor's organization, PEO IWS 1. Based on interactions with the sponsor, a tentative list of primitive needs was established. This list was further refined through site visits to PEO IWS 3 and interaction with several key defense contractors. User needs were developed through conversations with stakeholders and the author's Aegis experience, which includes eight years as an Aegis FCS/ORTS technician and two years as an Aegis fire control officer.

As the concept was developed further, additional stakeholder interaction was conducted to help refine the analysis. Meetings with key personnel at Commander, Naval Surface Forces in San Diego were held to refine the scenarios and functional definitions

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[14] "Large Map," *United-States-Map.com*, accessed June 13, 2014, http://www.united-states-map.com/tabloid.htm.

as they were being developed. Focused discussions were conducted with engineers at the Naval Surface Warfare Center in Port Hueneme to assist in refining the problem statement and to identify problems with the overall concept of operations. These informal meetings and discussions helped to steer the progress of the thesis and provided valuable insight into potential issues the STM could face.

1. Stakeholder Identification and Needs

To determine system needs, stakeholders were arranged by type, and their various primitive needs analyzed to determine effective needs to be addressed. Table 1 presents an initial analysis of stakeholder needs, as determined through various forms of interaction. The primitive needs represent desired outcomes, with no means specified. From these, effective needs were developed. The effective needs address the underlying problems of the primitive needs but have been refined in such a way that means are more readily identified to address them. As indicated in Table 1, the primitive needs of the sponsor and the users can be refined into fairly similar effective needs.

STAKEHOLDER TYPE	EXAMPLE ENTITIES	PRIMITIVE NEEDS	EFFECTIVE NEEDS
SPONSOR	PEO IWS, OPNAV	To maintain readiness in prolonged fiscally constrained environment. To train, equip, and maintain ships such that they are capable of combat operations.	To develop a very low cost, effective means of testing the readiness of installed combat systems equipment. To develop a means to conduct high-fidelity training events.
USERS	COCOMs, Numbered fleet commanders, Commodores	To supervise the readiness of ships assigned. To ensure maintenance and logistics requirements are being met for assigned ships.	To have a means available to rapidly verify the readiness of an individual ship's combat systems suite.
	Ship COs, Sailors, Technical Representatives	Confidence and competence in the operation of installed Combat Systems.	To be capable of rapidly, accurately, and safely determining the status of installed combat systems
PRODUCERS	Raytheon Missile Systems, ATK, BAE, Lockheed Martin, Others	To provide customers with safe and reliable products that fulfill one or more needs.	To maintain technological advantage over competitors. To procure sufficient profit margin to fund continued R&D.

Table 1. Stakeholder Identification and Needs

This initial analysis of primitive and effective needs was utilized to develop an initial concept of operations and to further refine the draft problem statement. Additionally, the effective needs were further refined into system needs, which will later be utilized in determining desired functionality and requirements. As illustrated in Table

2, the system needs were decomposed into means of implementation, which will guide the initial functional decomposition and requirements generation for the conceptual system.

STAKEHOLDER	SYSTEM NEEDS (FUNCTIONS & REQUIREMENTS)	IMPLEMENTATION OF SYSTEM NEEDS
SPONSOR	Develop a low cost round that approximates the performance and systems interfaces of Surface-to-Air missile systems currently in use.	Feasibility of reusability examined. Utilize existing components such as canister and solid rocket motor. Leverage the ubiquity of low-cost processing power and open architecture to lower cost for guidance and control subsystems. Pursue joint application and FMS to increase acquisition quantity to further drive down costs.
USERS	Firing rage flexibility. No requirement for non-organic range clearance platforms prior to firing event. Rapid data extraction after firing events. Ability to share firing test results with remote support activities. Ability to recover the expended round rapidly and safely with organic capabilities. (Helo or RHIB)	Maximum range limited through size of propellant charge in SRM. Onboard data recording subsystem outputs formatted data immediately following test event. Airframe designed with the safety and efficacy of recoverability emphasized.
PRODUCERS	Meets needs of widest possible user base. Design focused on produceability and ease of overhaul/refurbishment.	Flexible design that incorporates the ability to reconfigure onboard electronics package to simulate a wide variety of commonly used joint and foreign missile systems.

Table 2. Stakeholder Derived System Needs and Implementation

The needs of each stakeholder type contribute slightly different functional system needs. These needs are further explored in the following paragraphs.

a. Sponsor Needs

As the primary sponsor, PEO IWS seeks to achieve higher readiness for the AEGIS fleet without incurring the same level of cost and depletion of the existing inventory entailed by continued fleet proficiency firings using the Standard Missile (SM). To that end, a system designed to meet these needs would have to offer sufficient fidelity and readiness benefits at a lower cost than the SM. To meet that need, a number of options are available. Existing components can be utilized, reducing the extent and thus cost of research and development. Specific components that should be examined for integration include the Solid Rocket Motor (SRM) and VLS canister. There already exist SRM designs that could be adapted for use with the STM. Examples include the SRMs used for the ESSM and the NSSM. These rocket motors are already certified for use within VLS, further reducing test and evaluation costs.

Another avenue to pursue to lower cost is the early involvement of joint and allied forces in research and development. The United States Navy is not the only allied force entering a period of relative austerity, and if this concept can lower the cost of conducting live-fire testing, it is highly likely there would be considerable interest in foreign military sales (FMS). Likewise, if the concept is capable of being adapted to other combat systems, joint missile systems such as Patriot could derive benefit. Early involvement by these parties would serve to share research and development costs as well as increasing the overall acquisition numbers. Increased total acquisition would serve to further reduce per-unit cost, and will be discussed further in Chapter VI.

b. User Needs

User needs are considerably more specific than sponsor needs. One of the foremost considerations is, of course, the safety of usage for such a round. The round must be safe in every phase of its usage. The rocket motor must be capable of being made safe for handling operations. The canister must be Hazards of Electromagnetic Radiation to Ordinance (HERO) safe, rugged, and compatible with existing launcher safety mechanisms. In flight, the round must not deviate from controlled flight, and a means to conduct an emergency flight termination on command is a requirement. Post-flight, the recovery methods must be safe and expeditious, and the round must have a means to be stabilized for transport to an overhaul facility.

Another key user need is greater flexibility in firing ranges. Reducing the maximum range of the round to within the visual line-of-sight of the ship removes the requirement for non-organic range clearance assets by effectively reducing the size of the range to the firing unit’s visible horizon. Additionally, the time required to clear the firing range would be significantly lessened, allowing time for additional training requirements or for carrying out other duties assigned. The relaxed range requirements would also be of utility in the case of emergent combat systems casualties while deployed.

A final need is the requirement to be able to rapidly identify and localize faults within the firing unit’s combat systems suite. This calls for a hardware and software design that enables the easy transfer of formatted data from a firing event to both technicians on the firing unit as well as remote technical support organizations.

c. Producer Needs

Producer needs are focused on the economic aspects of the production of the STM. To meet the needs of the producers, sufficient numbers of the STM must be acquisitioned to make production economically viable and minimize costs. Considerations for the sponsor and user needs must not negatively impact the producibility of the round to an extent that profit is impacted.

Implementing this will require that the round be sufficiently flexible from a hardware standpoint that as many potential users are available as possible. For instance, if with minor modifications the round could be made to be compatible with the Patriot Missile System, an entirely new customer base is established with a minimum of cost required for retooling or software changes. Similarly, if FMS are authorized earlier versus later, additional contracts can be made for the sale and servicing of rounds, increasing the production quantity and lowering costs for all customers through learning curve and production rate effects.

C. PROBLEM STATEMENT

Based upon stakeholder analysis, the following problem statement was developed: Live-fire missile exercises are essential to verify system readiness and increase crew proficiency, but rising costs and declining inventory threaten the long-term feasibility of doing so. The project objective is thus: Confronted with a constrained fiscal situation, develop a means of conducting fleet proficiency firing events more frequently and at reduced cost. The specific means to be investigated in this thesis is a system-of-systems composed, in part, of a surrogate test missile designed to be recoverable and reusable. This missile will be compatible with all current baselines of the AEGIS weapons system, with allowance for future upgradability to support Air and Missile Defense Radar (AMDR) and Zumwalt configurations, among others.

The STM system of systems has the potential to increase readiness and reduce the risks associated with test and combat firing events. The increased readiness could be realized in two ways: 1) through increased watchstander experience and competence, and thus confidence, and 2) through the exhaustive pre- and post-fire maintenance checks conducted for a live fire exercise. The reduction in risk is a function of detection of fault conditions prior to either test firings (utilizing actual missiles) or deployment to a combat zone.

D. SCOPE

1. Scope and Context of Thesis

This thesis will examine the feasibility of the construction and utilization of a system of systems composed of a surrogate test missile and its associated recovery and support equipment. Cost estimation will be conducted in support of a tentative cost-benefit analysis. The required functionality for such a system will be decomposed, and form will be matched to function. Alternatives will be analyzed to the extent that they currently exist. Test and evaluation consideration for such a system will be briefly covered as well.

Additionally, discussion of various extended capabilities that could be considered for inclusion will be included. This includes, but is not limited to, the potential for FMS and pursuing joint involvement. Life cycle considerations for such a system of systems will be covered in depth.

Figure 4. High Level Surrogate Test Missile System Context Diagram

Figure 4 illustrates the context and boundaries of the Surrogate Test Missile System (STMS). Each boundary interaction, indicated by the blue arrows, is provided with system-level considerations that must be addressed for the STMS to function safely, reliably, and effectively. This initial context diagram allows operational considerations for the employment of the STMS to be envisioned, and helps to further refine the scope of this thesis.

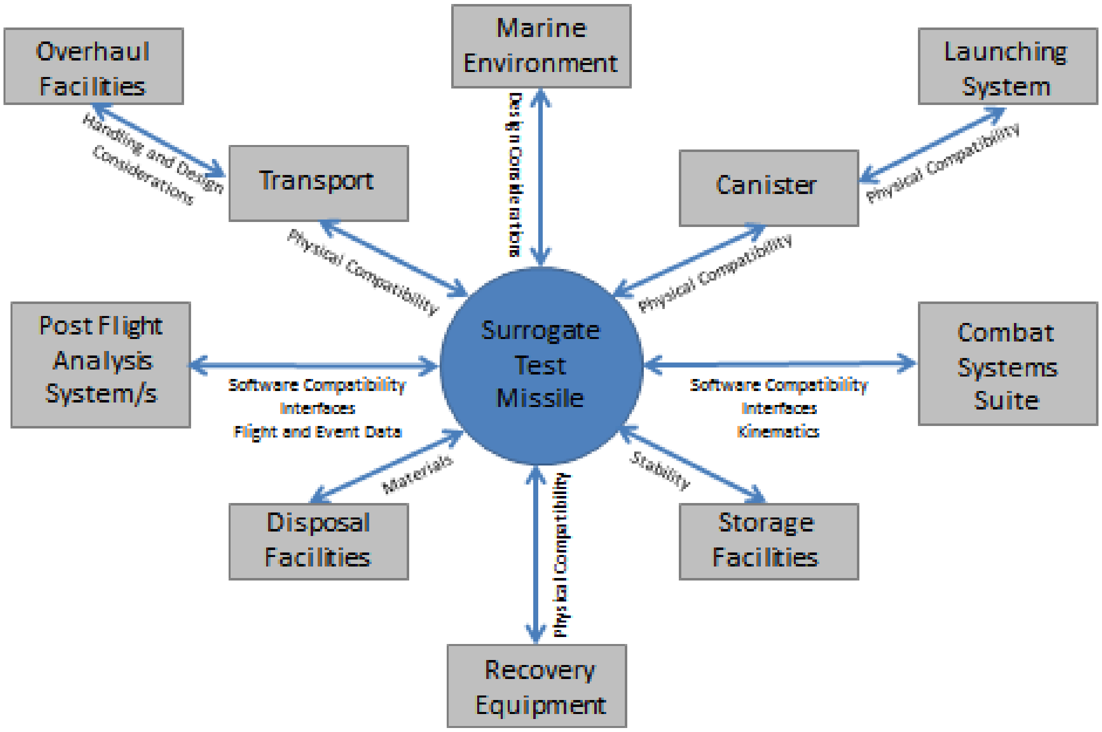

Figure 5. Detailed context diagram for the Surrogate Test Missile.

Figure 5 builds on the higher-level context diagram in Figure 4, and details the critical interface considerations for the STM itself from a System-of-systems perspective. The arrows again represent boundaries over which information, physical matter, or energy is exchanged. In developing this context diagram, potential problems are highlighted, especially when considering interfaces. For instance, when evaluating how the missile will be made compatible with various launching systems, the canister used in that launching system must be considered, along with the various interfaces between the missile and the canister and between the canister and the launching system.

2. Out of Scope

This thesis delves only superficially into an examination of available alternatives, as its primary purpose is the investigation of the feasibility and cost/benefit of one specific alternative. Detailed analysis of alternatives, as conducted during the JCIDS process, is deferred for further study. Similarly, cost estimation is conducted via the analogy method only, utilizing recent missile acquisition program data. A more detailed parametric or engineering approach is also deferred for potential follow-on studies.

This thesis concentrates primarily on development of the STM for use with the AEGIS weapons system, and investigates potential modifications for other combat systems or joint usage only superficially. Functional decomposition is primarily focused on the specific variant to be used with AWS, although adapting these functions to another weapons system should be considerably simplified by the identification of core functionalities required for effective operation.

Other items of discussion outside the scope of this thesis include prototyping, contracting, and reliability and availability analysis. Additionally, in the interest of minimizing the level of classification of this thesis, specific capabilities and limitations of the AEGIS weapon system, and other weapons and weapons systems, are either generalized or not discussed.

3. Limitations

The primary limitations of this thesis are the allotted timeframe, resource access, and expertise level of the author. The author of this thesis is not an aerospace engineer and has no experience outside of the academic setting with weapon systems acquisition. This thesis is strictly based on a systems engineering approach to an identified problem. All discussions of functionality, concepts of operations, requirements, and life cycle considerations will benefit greatly from an independent review and validation by experts in the specific fields involved. Whenever possible, the author attempted to reach out to stakeholders with the required expertise to fill in knowledge gaps, but given the conceptual nature of the system being examined, it is likely that more feasibility studies are required if it is desired to bring this system to fruition.

E. CONCLUSION

The preceding analysis identified the key stakeholder needs, defined the problem the remainder of this thesis addresses, and outlined the scope and limitations of this thesis. The specific problem to be addressed is simply to develop a low-cost, safe and effective means of conducting fleet proficiency firings. Any proposed solution must be cost effective, operate safely, and, most importantly, be effective in assessing and thus improving the readiness of a given combat system in order to address the key needs of the stakeholders. Having established the scope and boundaries of the problem space, defined the problem, and established the effective needs for the system, the next step is to begin identifying required system functionality through the development of scenarios and an overall operational concept.

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III. INITIAL CONCEPT OF OPERATIONS

A. EXPLORATION OF CONCEPTS

Developing a basic initial concept of operations, usage scenarios, and vignettes is helpful in determining the required functionality of a system or systems. Taking the problem statement, context diagram, and stakeholder input and analyzing them, the concept is next explored from a usage standpoint to identify what it must do in order to meet the identified needs of the various stakeholders.

1. Example Concept of Operations

The STM is envisioned as a “wooden” round, requiring no periodic maintenance for long time periods (i.e., more than five years) once it is placed in its canister. Ships typically will not deploy with the STM, but rather, the round will be loaded specifically to conduct a test or training firing event. Following the firing event, the empty canister will be removed and replaced with the desired missile type. Between firing events, STMs will be held in reserve at Naval Weapons Stations, with further rounds available at select overseas locations to facilitate emergent testing and/or proficiency requirements for deployed units. Potential locations for storage of STMs for use by naval forces around the globe are depicted in Figure 6.

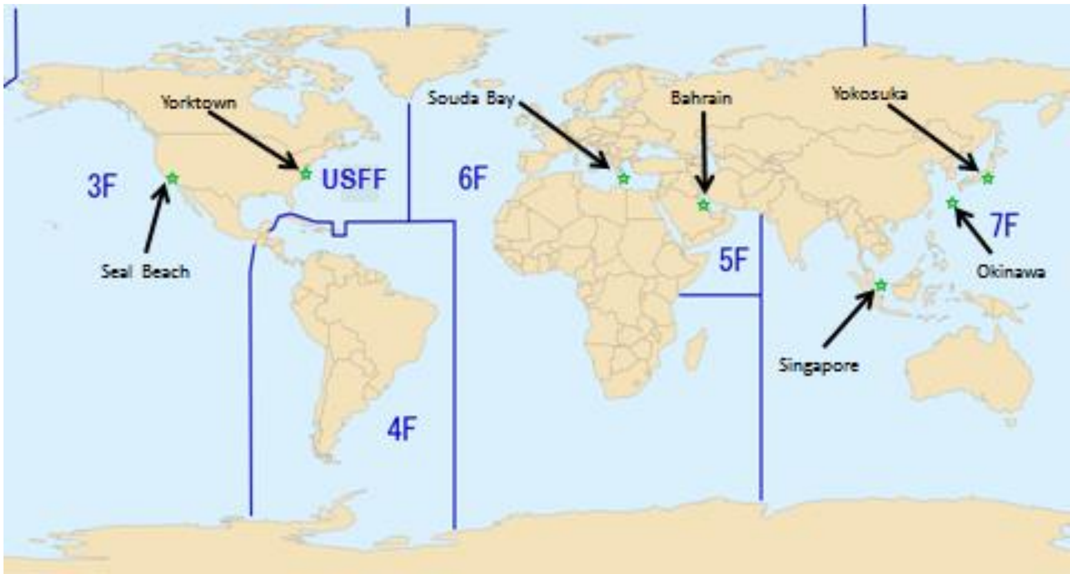

Figure 6. Potential CONUS and forward staging bases for Surrogate Test Missiles.

Once loaded, the STM will be checked out by shipboard VLS personnel to verify its functionality. Assuming all built-in test (BIT) functions check out properly, the round will be cleared to be fired. Should any BIT failures be noted, the round will be immediately off-loaded and flagged for maintenance. Once the round has been cleared for firing, the ship's Missile Systems Supervisor or equivalent watchstander will build a manual firing sequence, selecting the STM as the first missile in the firing sequence.

The ship loaded with the STM will proceed to a designated firing range. Due to the decreased maximum range and altitude the STM is capable of relative to the SM, the ship will be capable of conducting range clearance using only installed sensors - without the need for non-organic clearance support assets. If target drone assets are available, the launch of one will be coordinated. If no BQM (target drone) assets are available, the missile will be capable of flying a preset flight profile against an AN/SPY-1 test target (or equivalent synthetic target) while still being capable of verifying the functionality of uplink/downlink and terminal guidance.

If a BQM is available, it will be set to fly an anti-ship cruise missile (ASCM) profile and will be launched once the range is declared clear. Once the target is detected and tracking commences, a final check of range clearance will be conducted. If clear, the

Commanding Officer of the firing ship will declare “Batteries Release” for STM firing. The target will be engaged, and the STM launched, such that its point of intercept is approximately 10nm distant from the firing unit. During the boost phase, the STM will establish uplink with the firing unit’s combat system and begin recording all received commands as well as transmitted status updates. Additionally, all flight dynamics will be recorded, to include acceleration and positioning of flight control surfaces.

During the midcourse phase, the STM will continuously monitor midcourse guidance updates, recording time of receipt, content of command, signal amplitude, and range from firing unit. As the STM descends toward the point of intercept, an altimeter will monitor and record the distance to the surface. A programmable minimum altitude may be activated prior to launch to increase safety. As the STM enter the terminal phase, it receives, measures, and records the amplitude of received continuous-wave illumination (CWI) from both the rear reference beam and the main beam reflection from the target. Because the purpose of the STM is to verify the functionality of the firing unit’s combat systems, the engagement does not need to be consummated to the same level of accuracy as when simultaneously testing the efficacy of the weapon, such as when firing a warhead compatible telemeter (WCT) -equipped SM-2. For that reason, outside of obtaining accurate readings of the amplitude of the reflected main beam CWI, there is no need for the missile to approach closer than a few hundred feet from the target.

Upon reaching the closest point of approach with the target drone, the STM will immediately pitch upward and climb to bleed off, or aerodynamically reduce, airspeed. A drogue and parachute will slow the airframe as it descends. Once in the water, a transponder will activate and a sea dye marker will deploy to assist recovery personnel. Recovery will be possible using either a helicopter or a rigid-hull inflatable boat. In either case, a search and rescue (SAR) swimmer will deploy into the water and attach a recovery sling to the STM airframe. This will allow the round to either be lifted vertically or towed astern of the RHIB for the return to the ship. If the recovery is done via helicopter, the STM will be lowered into a recovery cradle for transport back to shore. On the other hand, if it is towed via the RHIB, it will need to be lifted out of the water from alongside the ship and placed into its cradle. When the STM is recovered, shipboard personnel will be able to access its onboard data storage. After recovery and initial inspections are conducted, the STM will be thoroughly cleaned and rinsed with fresh water to limit corrosion effects caused by immersion in sea water.

Once the ship returns to port, the STM in its cradle assembly will be removed via crane onto the pier. The airframe will again be inspected to ensure it is safe for transportation. The assembly will be shipped to the nearest designated overhaul facility. On arrival, the STM will be thoroughly inspected for damage, wear, and metal fatigue. The onboard electronics packages will be tested, and all electronics enclosures inspected for water intrusion. If all inspections are satisfactory, the STM will have its solid rocket motor replaced, along with other required replacement items such as batteries and data storage media. Following a final check-out, the STM will be replaced into a refurbished canister and transferred to storage to await the next launch event.

The expended canister will be offloaded in port and replaced as required with a loaded canister. The expended canister will be inspected and then shipped to a designated overhaul facility for refurbishment. One area that bears further study is the feasibility and cost effectiveness of conducting a limited cleaning of the expended canister prior to capping the ends and shipping it for overhaul. BAE Land & Armaments Systems representatives report at times extensive corrosion caused by prolonged periods of exposure to missile exhaust residue in the Mk 13 canisters returned by the Navy. This corrosion often requires the installation of doubler plates, or welded reinforcements for the canister structure, which adds cost to refurbishment while simultaneously reducing the lifespan of the canister.[15] Alternatively, a more resilient ablative-type coating could be applied to the canister interior to limit the corrosive effects of the missile exhaust residue.

2. Training CONOPs

In addition to the actual rounds, procurement of several “wooden” STM rounds should be considered. These rounds, lacking actual electronics and rocket motors, would

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[15] Thomas Callies, Launching Systems Program Manager at BAE Systems, conversation with author, January 15, 2014.

instead be used for training personnel who handle the rounds, either in the factory overhaul and inspection environment, or for training SAR swimmers to be proficient in handling the round in the water. For example, one or two wooden rounds could be maintained in the overhaul facility, and used to familiarize new maintenance personnel in the procedures used to inspect and refurbish the rounds. A canister could be used in conjunction with these rounds for training in mating procedures. Additional wooden rounds could be kept in fleet concentration areas and used for the training of SAR personnel. These rounds would be deployed, either in a pool or in open water, and used to gauge the proficiency of SAR swimmers as part of the SAR certification process. An additional round should be provided to the SAR schoolhouse for use in initial training of STM handling procedures.

B. SCENARIOS

The following scenarios were developed to illustrate potential avenues of fleet usage as well as to assist in the determination of any overlooked effective needs and requirements.

1. Sixth Fleet BMD Casualty

USS Ross is conducting a routine patrol in the Eastern Mediterranean in support of BMD operations when her C&D cooling skid fails. Due to a broken wire in the skid alarm panel, the alarm is not transmitted to Combat Systems Maintenance Central, and the first indication technicians receive of a problem is when AN/SPY-1 drops offline with a signal processor (SIGPRO) fault. Simultaneously, the SIGPRO over-temperature alarm sounds. Technicians respond and immediately secure power to the SIGPRO. Inspection reveals severe damage and melted solder in the backplane wiring of the SIGPRO. The casualty is determined to be beyond ship's force repair capability, and *Ross* is ordered to Souda Bay, Crete, for technical assistance. AN/SPY-1 technical representative are flown in from Italy and begin what becomes nearly 10 days of repairs.

As repairs are drawing to a close, 6th Fleet expresses concern as to whether or not *Ross* is fully mission capable and orders a STM to be fired to fully validate the AN/SPY-1 repairs. One of the two STMs stored at Souda Bay is delivered to the pier and lowered into *Ross'* VLS as repairs are ongoing. Upon completion of repairs, *Ross* stands to sea and proceeds to the NATO missile firing range just north of Crete. Arriving on station two hours late, following communications checks and a final check of system status, a shore-launched BQM-74 is intercepted successfully by the STM. *Ross* closes and recovers both the missile and drone. Ship's force technicians remove the data storage from the STM and within an hour of launch have all the data needed to declare the AWS onboard *Ross* as fully operational. Missile firing data is emailed to 6th Fleet along with a casualty correction message. After a brief stop in Souda Bay to offload the expended canister and load a SM-6, *Ross* stands out to sea and proceeds back to her station.

a. Scenario Challenges

Loading a test round into a VLS magazine loaded with live ordinance could be considered to violate one of the cardinal safety rules for VLS – that no simulator round shall be loaded in a launcher containing live ordinance.[16] It is unclear, however, if this rule, designed to prevent the inadvertent launch of live missiles when conducting training or testing, fully applies in this case. For one, the test missile would be selected in a manual firing sequence, just as current WCT-equipped missiles are. This selection will be verified by multiple watchstanders. Next, by only enabling the Canister Safe Enable Switch (CSES) on the test missile canister, only that singular missile will be capable of receiving the Launch Enable signaling to fire. Though some probability that the wrong missile will be selected and fired exists, this is a very remote probability. That probability can further be reduced by including clear labeling on the canister near the CSES switch that identifies the missile as a test round. Another way to minimize risk is to use a code plug that identifies the missile as a test round to the system, although to use a unique code plug would require software updates for VLS or WCS, or both.

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[16] Leo Schnieder, "VLS: A Challenge Met, An Old Rule Kept." (24th Annual Technical Symposium, April 1987), accession Number: ADA183944. http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA183944, 12

2. CSSQT Certification

The *USS Comte De Grasse*, DDG 125, is weeks away from commissioning. As a new Baseline Flight III DDG, her AEGIS Weapon system has significant architecture and software changes. Due to this, she is scheduled to fire three Standard Missiles and two Evolved Sea Sparrow Missiles during her CSSQT firings. To ensure her system is prepared, she is also loaded with two STMs. One week prior to the SM firing events, she is ordered to sea to conduct a live firing event with the STMs.

Once at sea, a range clearance is conducted. Once the range has been declared safe, a BQM-74 is launched from her flight deck and proceeds down-range, then turns inbound and assumes an ASCM flight profile. The BQM is detected at the expected range, and as the intercept point passes within 10nm of the ship, the first STM is launched. Topside safety observers immediately note that the flight of the STM is erratic, with the round violently zig-zagging downrange. The SPY Radar System Controller observes the STM to miss the intercept point by an estimated two miles. Upon recovery and data extraction, technicians note that the midcourse guidance commands from SPY were wildly inconsistent. Investigation reveals a faulty signal generator which was inserting random phase shifts that went undetected by installed fault detection equipment. The part is replaced, and the next STM firing is a complete success. *Comte De Grasse* is cleared to conduct follow-on SM firings.

a. Scenario Challenges

Similar to the first scenario, this scenario would require mixing test and live missiles. However, because this is a more limited test scenario, the number of missiles involved would be such that it would be possible to keep the STMs and the other ordinance separated in different launchers. For example, the STMs could be loaded in the forward launcher, and the ESSMs and SMs could be loaded in the aft launcher.

3. Fleet Proficiency Firing

The *USS Donald Cook*, as part of its training cycle, is selected to do a live firing event for watchstander proficiency. As it is forward deployed to Rota, there is a lack of

BQM assets to support the proficiency firing. As a result, this training firing will utilize a modified Scan Eagle drone that has been outfitted with radar cross-section augmentation to give it the approximate RCS of a typical Low Slow Flyer threat. *Donald Cook* gets underway from Rota and proceeds approximately 70nm into the Gulf of Cadiz. Upon clearing the range visually and electronically, the Scan Eagle is launched from the flight deck. Its onboard cameras are used to visually clear the range as it proceeds approximately 30nm from the ship before turning and heading inbound.

As the Scan Eagle approaches the ship, it is detected on radar. The observed Low Slow Flyer profile, along with intelligence injections that detail the threat, prompts the watchteam to step through their required actions. Because the intelligence suggests that this threat could potentially be carrying chemical weapons, the decision is made to engage the threat as soon as it is visually identified. The CIC watchteam conducts queries and warnings on the inbound target, stepping through the procedures they would use if faced with an actual threat. As the target approaches 10nm, the bridge watchteam verifies to CIC that the tracked target is the threat platform identified by earlier intelligence, and the CO gives the watchteam batteries release. As the threat passes through 10nm, the STM is fired at the Scan Eagle. All systems perform to specification, and both the Scan Eagle and STM are recovered prior to the *Donald Cook* returning to port.

a. Scenario Challenges

Due to the reduced range of the STM relative to the Standard Missile, training events would necessarily lose some fidelity when the STM is fired in lieu of the SM. For instance, against an ASCM, the SM would be fired almost immediately upon detection of the threat, while use of the STM would require that the "recommend fire" alert not be acted upon until the intercept point reaches the maximum range of the STM. This is not "Training how you fight," and some concern has been expressed by Commander, Naval Surface Forces and others that this could diminish the training quality received by proficiency firings.

This scenario presents one way to minimize that concern by presenting a non-traditional training scenario in which a SM would conceivably be used. Additionally, the use of the low-cost Scan Eagle as a target is a novel way to get around a lack of ASCM-type target availability while still providing training against relevant threats such as terrorist-controlled LSF aircraft and UAVs such as the Harpy.

4. Fire Control System Failure Vignette

During a post-drydock availability firing event, *USS Arleigh Burke* expends a STM against a BQM-177. As the interception enters the terminal phase, Illuminator #2 is assigned to the target. However, when the transmitter cycles up to Radiate, it immediately drops offline with a travelling wave tube (TWT) fault. WCS then assigns Illuminator #3, but it too fails due to a faulty train gyroscope. The target is in the cutout for Illuminator #1. The STM, upon detecting no expected passive homing radiation, immediately climbs to a safe altitude to prevent inadvertent collision with the target drone. Upon recovery, all AN/SPY-1D data is determined to be nominal, and the ship's combat system is declared fully operational once the faulty Mk 99 fire control systems are diagnosed and repaired.

5. Parachute Failure Vignette

After a nominal interception against a BQM-74E, the STM pitched up as expected, but a solenoid failure caused the parachute to fail to deploy properly. The STM tumbled downward over 8000 feet, slowed only by a partially deployed drogue, before forcefully impacting the water. The recovery beacon activated as designed and the firing unit closed and placed a SAR swimmer in the water to assess the damage. The airframe, although warped by impact, was mostly intact, so the recovery harness was attached. An SH-60 helicopter lifted the round and placed it on the flight deck, as it was too damaged to properly fit in its cradle. Shipboard technicians accessed the data storage compartment and were able to download all firing data. The missile was returned to the overhaul facility, where useable components were removed prior to the damaged airframe components being scrapped.

C. DESIGN REFERENCE MISSION

The design reference mission (DRM) for this concept, derived from the scenarios and vignettes, consists of three distinct phases: preflight, firing event, and post-flight. The Preflight phase consists of the transportation of the STM to the designated firing unit, where the STM is loaded into the launching system and built-in test functions are used to determine its status. Following these events, and conditioned on the STM passing all testing, the firing unit leaves port and transits to a suitable firing range. Range clearance checks are conducted to ensure no surface or air traffic will conflict with the flight of the STM or the target drone (if utilized). The firing event phase begins with the launch of the target drone and its subsequent detection and identification by the firing unit's combat systems suite. As the target drone proceeds inbound, it is engaged, and the engagement is consummated once the predicted intercept point is within 10nm of the firing unit. The STM flies out, responding to transmitted commands from the firing unit. Upon intercept, the STM decelerates and enters the water. The post-flight phase begins upon water entry, with splashdown and the subsequent activation of the recovery beacon. The STM is then recovered by either the firing unit or a designated recovery platform. All firing data is extracted and uploaded, and the recovered airframe is then transported to shore for further transit to an overhaul facility. The canister is removed from the firing unit, thoroughly cleaned to prevent corrosion from rocket exhaust residue, and transported to the overhaul facility. The post-flight phase ends upon completion of post-firing maintenance on the STM and canister with the STM checked out and cleared for another firing event. Due to the nature of this conceptual round, there is no need for additional design reference missions. The STM is strictly designed to provide confirmation of the operability of combat systems suites and their associated firing chain. Testing will not be conducted in conjunction with combat operations, in inclement weather, or under any other circumstances that would necessitate the development of more robust reference missions.

D. SUMMARY

The analysis conducted in this chapter provided an initial concept of operations, from which a design reference mission was extrapolated. The various scenarios presented assist in the identification of required functionality. Key challenges that must be addressed are the safety of utilizing the STM within VLS and developing effective and realistic training scenarios. By exploring how the STM would be used, the critical system needs can be extracted and analyzed via a detailed functional decomposition.

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IV. FUNCTIONAL ANALYSIS

A. FUNCTIONAL DECOMPOSITION

The process of thinking through several usage scenarios and developing a concept of operations led directly to the identification of required operational system functions. To narrow the scope of this analysis, the majority of the functions here described pertain to the Surrogate Test Missile only, with functional requirements for other components of the Surrogate Test Missile System addressed only superficially. To fully develop these functions, a functional decomposition of the STM was first performed, identifying the major functionalities that must be performed to ensure the concept performs properly and safely. This chapter decomposes the various required functions and describes the means by which selected functions would be accomplished.

1. Top-level Functional Definitions

The STM concept, to be successful in its primary goal of verifying the readiness of a combat system, must be capable of multiple, specific functions. To explore the required functionality, an Aegis-compatible missile was examined. The required functions derived specific to Aegis would, of course, have analogs for a STM designed to support another combat system. For instance, a STM configured to simulate a NSSM may need to be capable of receiving and measuring Mk 95 CWI FCS guidance rather than that from an AN/SPG-62. Keeping that in mind, the top-level functional decomposition for the STM is depicted in Figure 7:

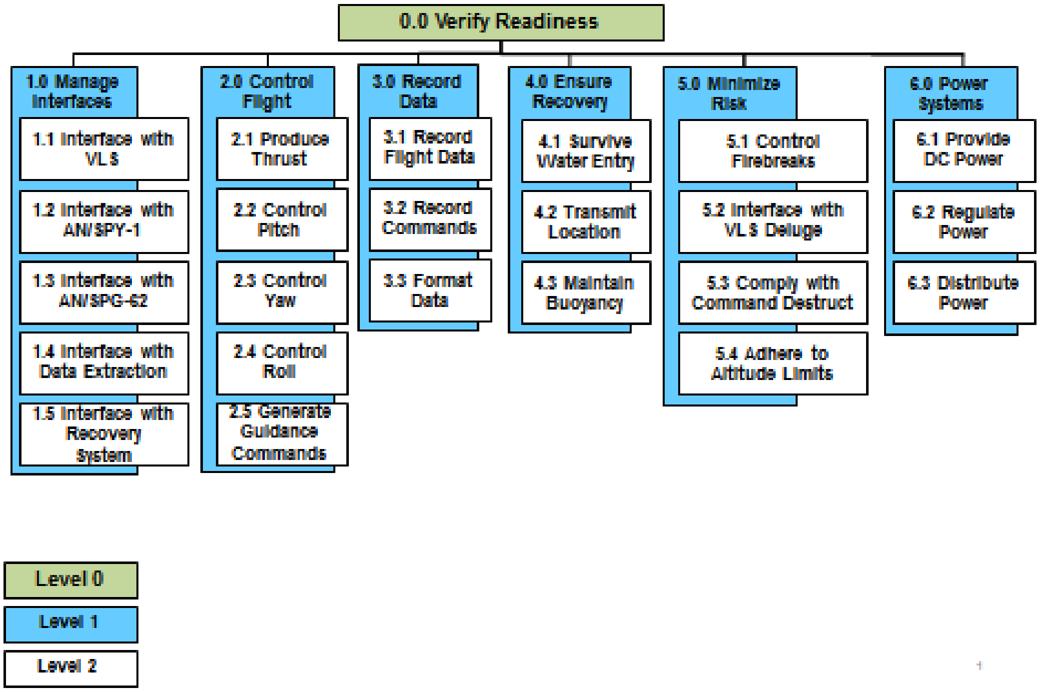

Figure 7. Top Level Functional Hierarchy of AEGIS-Configured STM

Manage Interfaces: This function denotes the requirement that the STM provide a means, physical or otherwise, for connecting to, receiving data and commands from, and reporting status to a number of shipboard Combat System elements. The sub-functions included are specific to AEGIS, but would have analogs if the STM was configured to function with a different combat system. In this particular case, the (1.1) subfunction, Interface with VLS, describes the requirement to physically and electronically interface with the Vertical Launch System, to include the Launch Sequencer (LSEQ) and Launch Control Unit (LCU). Further physical interfaces are implied, including but not limited to gas management, deluge, and umbilical. Further, the interface would require a code plug that correctly identifies the missile to the VLS computer system. The (1.2) subfunction, Interface with AN/SPY-1, describes the requirement for compatibility with AN/SPY-1 missile uplink and downlink transmissions. The (1.3) subfunction, Interface with AN/SPG-62, describes the requirement for a capability to receive AN/SPG-62 terminal homing CWI radiation, to include rear-reference reception. The (1.4) Interface with Data Extraction subfunction describes the requirement to be capable of transferring collected data to a designated subsystem. This could be as simple as transferring a memory card into a laptop computer, or wirelessly transmitting recorded data back to terminal. Finally, the (1.5) subfunction, Interface with Recovery Systems, describes the physical interface requirements for the STM's recovery subsystems, specifically the lifting sling and transport cradle.

Control Flight: This function describes the requirement for the STM to maintain controlled flight. The (2.1) subfunction, Produce Thrust, describes the requirement for a source of both boost and sustainment thrust to propel the STM downrange. The (2.2), (2.3), and (2.4) subfunctions, Control Pitch, Yaw and Roll, describe the requirement for control of the attitude of the airframe in flight. The final subfunction, 2.5, Generate Guidance Command, describes the requirement that both programmed maneuvers (Such as tipover, flare, and others) and remote guidance commands can be processed and translated into appropriate control surface actuation.

Record Data: This function describes the requirement that data relevant to the readiness or training evolution being conducted is recorded for later analysis. The (3.1) subfunction, Record Flight Data, describes the need to gather and save all telemetry data from the flight, to include acceleration commands, positioning of control surfaces, and relevant events, such as rocket motor burnout. The (3.2) subfunction, Record Commands, describes the required capability to record all externally generated commands received by the missile. These could include midcourse guidance commands and terminal homing. The final subfunction, (3.3), Format Data, describes the requirement that all collected data, whether digital or analog, be properly formatted to expedite future analysis.

Ensure Recovery: This function describes the requirement that the STM be survivable, such that it may be recovered for later reuse. The subfunction (4.1) describes the requirement that the airframe survive impact with and submersion in seawater. Implicit in this subfunction the requirement that sufficient water-tight integrity is maintained to prevent water intrusion into sensitive electronics compartments. The subfunction (4.2), Transmit Location, describes the required function of broadcasting, either visually or electronically, the location of the airframe after water entry to facilitate recovery. The (4.3) subfunction, Maintain Buoyancy, describes the requirement that sufficient buoyancy be maintained while in the water to support the airframe at the surface. Implied in this requirement is that the buoyancy will be distributed such that an attitude conducive to recovery is maintained.

Minimize Safety Risk: This function describes the requirement that the STM shall be safe for usage by fleet units. Despite lacking a warhead, a solid-rocket motor is inherently a potential hazard in a maritime environment, and adequate safety is required during all phases of the STM's life cycle. The subfunction (5.1), Control Firebreaks, describes the requirement that electronic firebreaks be utilized to prevent inadvertent firing of the STM. A system such as AEGIS has multiple electronic firebreaks, but this function should encompass multiple approaches to ensure that in the event the STM is used in a different configuration. The subfunction (5.2), Interface with VLS Deluge, describes the requirement that when utilized in a VLS configuration, the STM canister will be required to attach to the deluge system, if installed, to provide cooling in the event of a fire or restrained firing event. The subfunction (5.3), Comply with Command Destruct, describes the requirement that, if ordered, the STM shall terminate its flight promptly to prevent hazarding aircraft, surface vessels, or others. The subfunction (5.4), Adhere to Altitude Limits, describes the required function of adhering to programmed minimum and maximum altitudes to allow for safe operation.

Power Systems: This function describes the requirement that electrical power sufficient to operate all onboard subsystems shall be incorporated into the design of the STM. The (6.1) subfunction, Provide DC Power, describes the requirement that adequate Direct Current electrical power be provided to all subsystems for the duration of a flight cycle. The (6.2) subfunction, Regulate Power, describes the requirement that voltage and amperage be regulated to provide different subsystems with different power requirements the proper power. The (6.3) subfunction, Distribute Power, describes the requirement that regulated power be distributed to all required subsystems.

2. Detailed Functional Definitions

Having defined the top-level system functionality in the preceding section, the next step is to decompose the identified functions further. This detailed functional requirement will identify additional functional needs for the conceptual STM.

a. Manage Interfaces Function

Managing the various interfaces of the AEGIS combat system is a key functional need. Key interfaces that must be established and maintained for the STM to properly operate are shown in Figure 8.

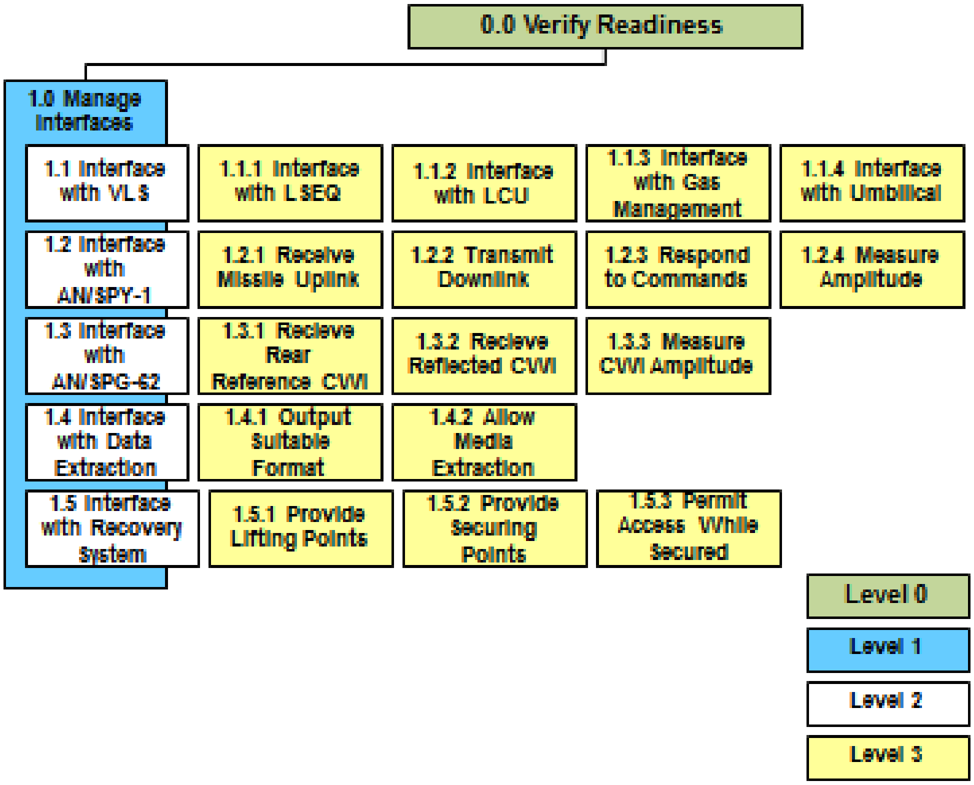

Figure 8. Detailed Decomposition of (1.0) Manage Interfaces Function

Interface with VLS: This function is comprised of the (1.1.1) and (1.1.2) Interface with LSEQ and LCU subfunctions. These describe the requirement that the STM software be compatible with and recognizable by the VLS subsystems such that the STM can be properly identified by the onboard Weapons Control System. The (1.1.3) subfunction, Interface with Gas Management, describe the requirement that the canister used for the STM must properly physically interface with the gas management subsystem of VLS. For instance, if a Mk 22 or modified Mk 13 canister is selected for use, the appropriate canister adapter must be present to route missile exhaust into the plenum assembly of the launcher. Inherent in this subfunction is the requirement that missile exhaust produced is within tolerances for operation within VLS. The (1.1.4) subfunction, Interface with Umbilical, describes the requirement that the common umbilical connector used in VLS be fully compatible with the STM canister.

Interface with AN/SPY-1: This function describes the requirement that all variants of the AN/SPY-1 radar be compatible with the STM. Its (1.2.1) and (1.2.2) subfunctions, Receive and Transmit Missile Uplink/Downlink, describe the requirement that the STM possess a transceiver capability coupled to onboard computing and software capable of receiving, processing, and correctly responding to midcourse guidance updates from the AN/SPY-1 radar system. The (1.2.3) subfunction, Respond to Commands, describe the requirement that midcourse guidance commands, command destruct, and other ordered functions be routed properly through the STM's onboard computing device such that the appropriate subsystems are properly directed. For instance, a command to alter course should generate a command to the flight control subsystem. The (1.2.4) subfunction, Measure Amplitude, describes the requirement that calibrated measurement of each received RF signal from the AN/SPY-1 radar shall take place for the duration of the STM's flight. This data will later be used to extrapolate the maximum range of coherence for AN/SPY-1 uplink.

Interface with AN/SPG-62: This function describe the requirement that the STM be capable of receiving and responding appropriately to Fire Control Continuous Wave Illumination (CWI). The subfunction (1.3.1) Receive Rear Reference CWI describes the requirement that the STM shall be capable of receiving the reference CWI signal output by the ancillary feedhorn of the AN/SPG-62. The (1.3.2) subfunction, Receive Reflected CWI, describes the requirement that the STM be capable of receiving the reflected main beam illumination from the target. The (1.3.3) subfunction, Measure CWI Amplitude, describes the requirement for measurement of the received signal intensity.

Interface with Data Extraction: This function describe the necessity to be capable of interfacing with a Data Extraction subsystem suitable for data analysis and firing test result display. The subfunction (1.4.1), Output Suitable Format, describes the requirement that collected data be compiled into a format that is suitable for rapid extraction and analysis. For instance, ordered deflection angle of the control surfaces over time could be compiled by the onboard software using Comma Separated Values (CSV), thus allowing the data to be imported into any number of open source software analysis programs. The subfunction (1.4.2), Allow Media Extraction, describes the requirement that onboard data recording media be easily accessible to allow for rapid post-mission data transfer.

Interface with Recovery System: This function describes the requirement that various recovery subsystems be physically compatible with the STM itself. The subfunction (1.5.1), Provide Lifting Points, describes the requirement that the STM be configured with accessible lifting points suitable for the attachment of a harness or strong-back type lifting device. This would facilitate easy lifting of the STM airframe by helicopter or crane, depending on the recovery method. The (1.5.2) subfunction, Provide Securing Points, describes the requirement that the STM airframe will be capable of being secured for transit, either to a cradle or within a shipment canister. This is a separate requirement from the method used to secure it within the firing canister. The (1.5.3) subfunction, Permit Access While Secured, describes the requirement that critical portions of the STM be accessible regardless of the securing method employed. This would permit data extraction and limited inspection, troubleshooting, and maintenance of the electronic subsystems of the STM while the airframe was secured.

b. Control Flight

The ability to maintain controlled flight is critical to the safe and effective use of the STM in a fleet environment. This top level function’s subordinate functions are detailed in Figure 9.

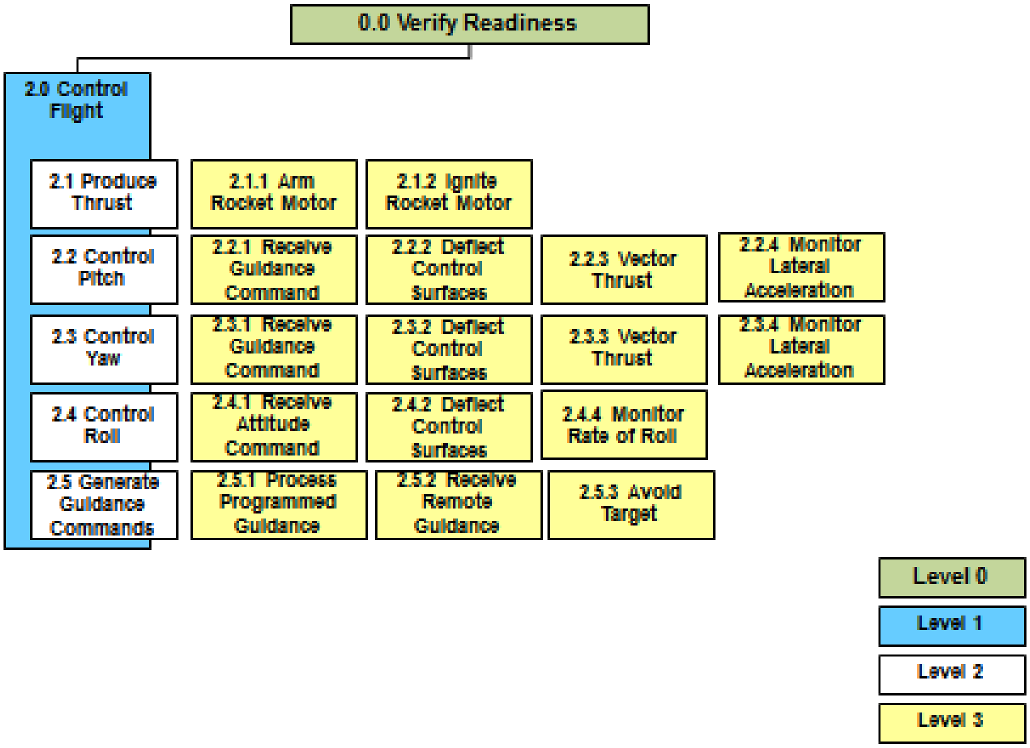

Figure 9. Detailed Decomposition of (2.0) Control Flight Functions

Produce Thrust: This function describes the requirement that the STM be capable of generating thrust to propel itself downrange. The (2.1.1) subfunction, Arm Rocket Motor, describes the requirement that, on command, the Rocket Motor be capable of being armed remotely for firing. The (2.1.2) subfunction, Ignite Rocket Motor, describes the requirement for the safe remote ignition of the rocket motor.

Control Pitch: This function describes the requirement that the STM be able to control its pitch attitude in controlled flight. The (2.2.1) subfunction, Receive Guidance Command, describes the requirement that the subsystem responsible for actuation of control surfaces be capable of translating programmed or remote guidance commands into orders for the control surfaces. The (2.2.2) subfunction, Deflect Control Surfaces, describes the requirement that control surfaces be actuated in such a manner that they produce the magnitude of pitch change needed to execute the guidance command. The (2.2.3) subfunction, Vector Thrust, describes the requirement that thrust vectoring be used, as applicable, either in conjunction with or independent of control surface deflection, to make pitch adjustments as required. The (2.2.4) subfunction, Monitor

Lateral Acceleration, describes the requirement that the magnitude of acceleration produced by control surface actuation or thrust vectoring is monitored and recorded.

Control Yaw: This function describes the requirement that the STM be capable of controlling the yaw of its airframe in controlled flight. The Subfunctions (2.3.1 – 2.3.4) are functionally identical to those described in “Control Pitch” but are related to a different axis.

Control Roll: This function describes the STM’s required ability to control the roll of its airframe in controlled flight. The (2.4.1) subfunction, Receive Attitude Command, describes the requirement that the control subsystem be capable of receiving roll attitude commands and translating them into proper actuation of control surfaces. The subfunction (2.4.2), Deflect Control Surfaces, describes the requirement that control surfaces be actuated in such a manner that roll control in maintained for the duration of controlled flight. The subfunction (2.4.3), Monitor Rate of Roll, describes the requirement that the airframe’s rate of roll is measured and recorded throughout the flight event.

Generate Guidance Commands: This function describes the requirement that appropriate guidance commands be provided to support safe controlled flight. The (2.5.1) subfunction, Process Programmed Guidance, describes the requirement that pre-programmed maneuvers are executed during flight. This would include adherence to both minimum and maximum altitude limits, missile tipover, and post-intercept pitchup. The (2.5.2) subfunction, Receive Remote Guidance, describes the requirement that the onboard guidance subsystem be capable of receiving remote guidance commands, either in the form of AN/SPY-1 midcourse guidance updates or AN/SPG-62 terminal guidance. The subfunction (2.5.3), Avoid Target, describes the requirement that the relative position to the target is tracked, and that the STM maneuvers to avoid collision with the target. This could be accomplished in any number of ways, from use of a transponder to tracking the intensity of the reflected CWI from the target.

c. Record Data

The ability to format and record significant flight and combat systems data allows the STM to contribute to the readiness of the firing unit. The subordinate functions of this top-level function are depicted in Figure 10.

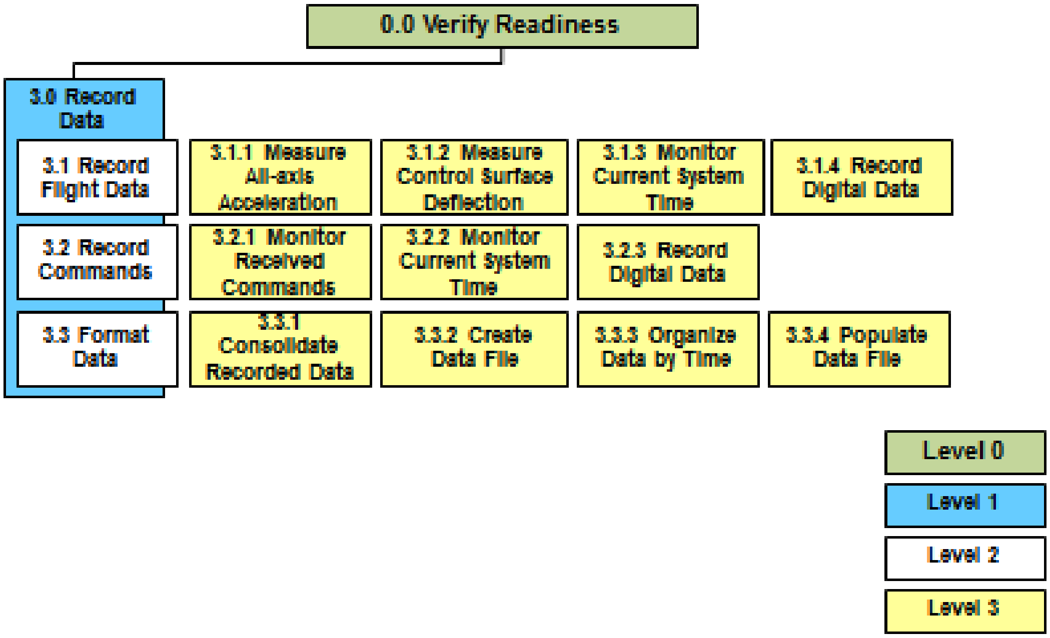

Figure 10. Detailed Decomposition of (3.0) Record Data Functions

Record Flight Data: This function describes the requirement that flight data of the STM be recorded for post-flight analysis. The (3.1.1) subfunction, Measure All-axis Acceleration, describes the requirement that acceleration forces experienced by the STM be measured and recorded. The (3.1.2) subfunction, Measure Control Surface Deflection, describes the requirement that deflection of control surfaces be measured and recorded. The (3.1.3) Monitor Current System Time, describes the requirement that an onboard clock be utilized to provide accurate time information for all recorded flight data. The (3.1.4) subfunction, Record Digital Data, describes the requirement that analog measurements of relevant flight data be converted to digital format for storage and later transfer.

Record Commands: This function describes the requirement that received commands be recorded. The (3.2.1) subfunction, Monitor Received Commands, describes the requirement that any command received via uplink is recorded for later analysis. The (3.2.2) subfunction, Monitor Current System Time, describes the requirement that an onboard clock be utilized to provide accurate time information for all recorded flight data. The (3.2.3) subfunction, Record Digital Data, describes the requirement that analog data (such as AN/SPG-62 intensity) be converted to digital format for storage and later transfer.

Format Data: This function describes the requirement that all recorded data be formatted to expedite transfer and analysis. The (3.3.1) subfunction, Consolidate Recorded Data, describes the requirement that recorded data be compiled into a common file or files. The (3.3.2) subfunction, Create Data File, describes the requirement that either pre-flight or post-flight, a file or files are created to organize recorded data. The (3.3.3) subfunction, Organize Data by Time, describes the requirement that timestamp data is associated with each data entry to allow reconstruction of flight events during analysis. The (3.3.4) subfunction, Populate Data File, describes the requirement that created files be populated with compiled data throughout the flight test event.

d. Ensure Recovery

Providing a means to safely and expeditiously recover the STM following a firing event is a key component in cost reductions realized through multiple firings. The decomposition of this top level function is depicted in Figure 11.

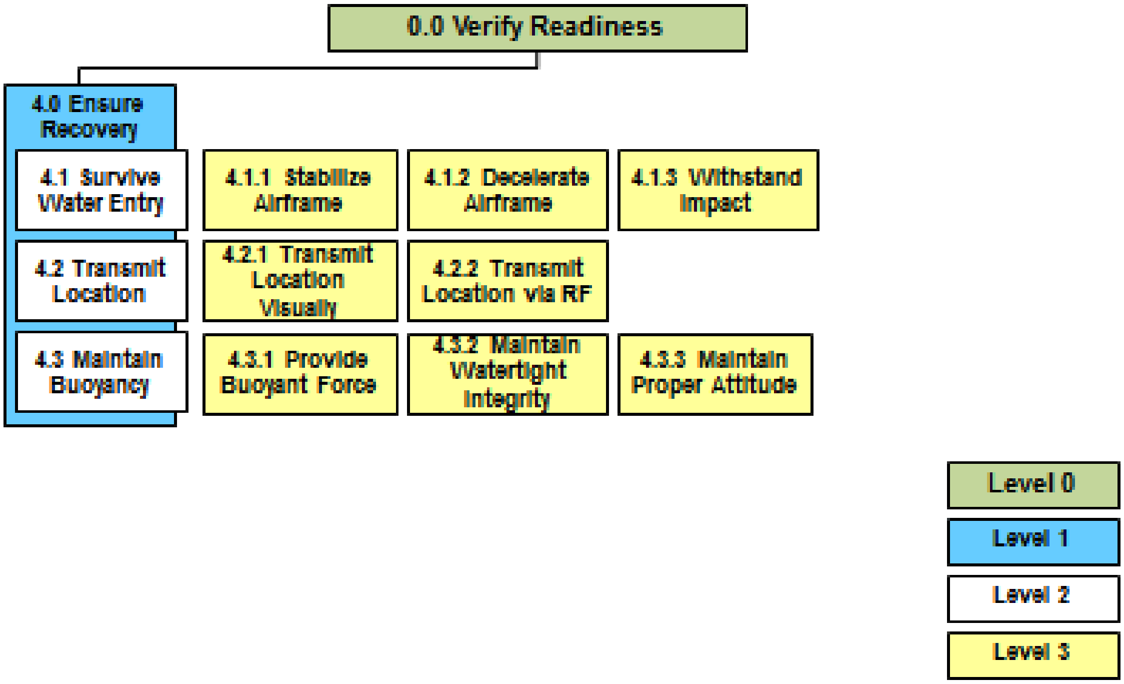

Figure 11. Detailed Decomposition of (4.0) Ensure Recovery Functions

Survive Water Entry: This function describes the requirement that the STM be designed to withstand the forces associated with water entry. The (4.1.1) subfunction, Stabilize Airframe, describes the requirement that, post-intercept, the airframe assume a controlled, stable attitude. The (4.1.2) subfunction, Decelerate Airframe, describes the requirement that the STM airframe be decelerated at a sufficient rate to prevent damage upon impact with the water. The (4.1.3) subfunction, Withstand Impact, describes the requirement that the airframe possess inherent structural integrity to withstand impact with seawater if stabilized and sufficiently decelerated.

Transmit Location: This function describes the requirement that the location of the STM post-flight be transmitted to facilitate recovery. The (4.2.1) subfunction, Transmit Location Visually, describes the requirement for a means of visually indicating the position of the STM in the water post-splashdown, such as via dye marker or flashing strobe light. The (4.2.2) subfunction, Transmit Location via RF, describes the requirement that an RF signal be transmitted post-splashdown of sufficient intensity to be received by aircraft or ships in the vicinity. This transmitted signal may either contain location information, or be simply utilized for direction finding.

Maintain Buoyancy: This function describes the requirement that the STM airframe possess enough buoyancy to remain afloat and to facilitate easy recovery. The (4.3.1) subfunction, Provide Buoyant Force, describes the requirement that sufficient buoyancy is provided to maintain the STM at the surface of the water. This could be accomplished via inherent buoyancy built into the airframe, with a separate subsystem that uses inflatable supports, or through some combination of the two. The (4.3.2) subfunction, Maintain Watertight Integrity, describes the requirement that water not be capable of flooding portions of the STM once in the water. This serves both to maintain buoyancy and to protect onboard electronic components. The subfunction (4.3.3), Maintain Proper Attitude, describes the requirement that the STM airframe assume and maintain an attitude in the water conducive to recovery efforts.

e. Minimize Risk

Minimizing the safety risks involved with utilizing the STM with VLS and in a fleet environment is critical to fulfilling stakeholder needs. The various subordinate functions that are required to mitigate potential risks to safety are shown in Figure 12.

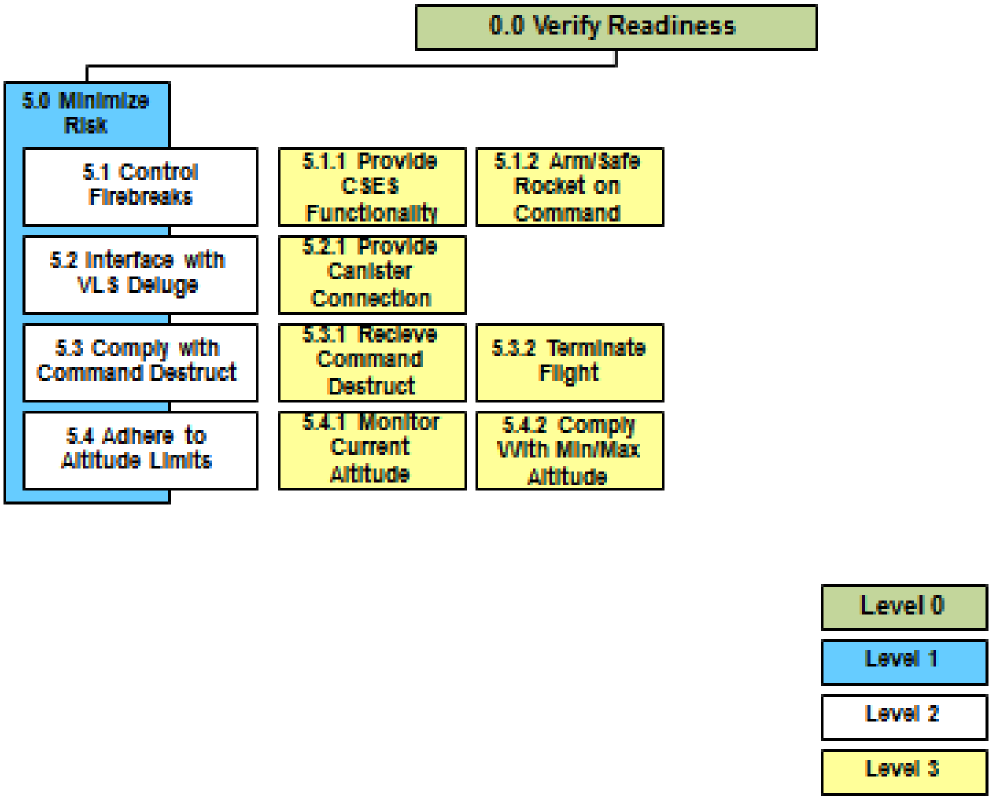

Figure 12. Detailed Decomposition of (5.0) Minimize Risk Functions

Control Firebreaks: This function describes the requirement that suitable firebreaks be installed to prevent inadvertent firing and safety during handling, storage, and at-sea operations. The (5.1.1) subfunction, Provide CSES Functionality, describes the requirement that a Canister Safe/Enable Switch be installed on the STM canister and interface with the STM such that when made safe, the Rocket Motor cannot be armed or fired. The (5.1.2) subfuntion, Arm/Safe Rocket on Command, describes the requirement that remote arming and safe/arm capability be provided for the rocket motor assembly of the STM.

Interface with VLS Deluge: This function describes the requirement that VLS deluge can be used on the STM in the event of a restrained firing. The only subfunction (5.2.1), Provide Canister Connection, describes the requirement that a connection be provided on the canister of the proper dimensions to accept VLS deluge.

Comply with Command Destruct: This function describes the requirement that remote termination of the STM in flight can be accomplished via AWS commands. The (5.3.1) subfunction, Receive Command Destruct, describes the requirement that the onboard electronics be capable of receiving, processing, and complying with a Command Destruct. The (5.3.2) subfunction, Terminate Flight, describes the requirement that the STM be capable of abrupt termination of flight upon receipt of a Command Destruct. This can be accomplished any number of ways, but it is important to note the lack of a warhead limits the options significantly.

Adhere to Altitude Limits: This function describes the requirement that programmed altitude limits are adhered to. The (5.4.1) subfunction, Monitor Altitude, describes the requirement that real-time altitude data be continuously monitored and compared to programmed altitude limits. The subfuntion (5.4.2), Comply with Min/Max Altitude, describes the requirement that the guidance and control subsystems work together to maintain missile flight within programmed altitude limits within a safe tolerance band.

f. Power Systems

Providing electrical power to the various subsystems of the STM is an overarching requirement for its operation. Figure 13 details the subordinate functions that ensure power delivery during STM operations.

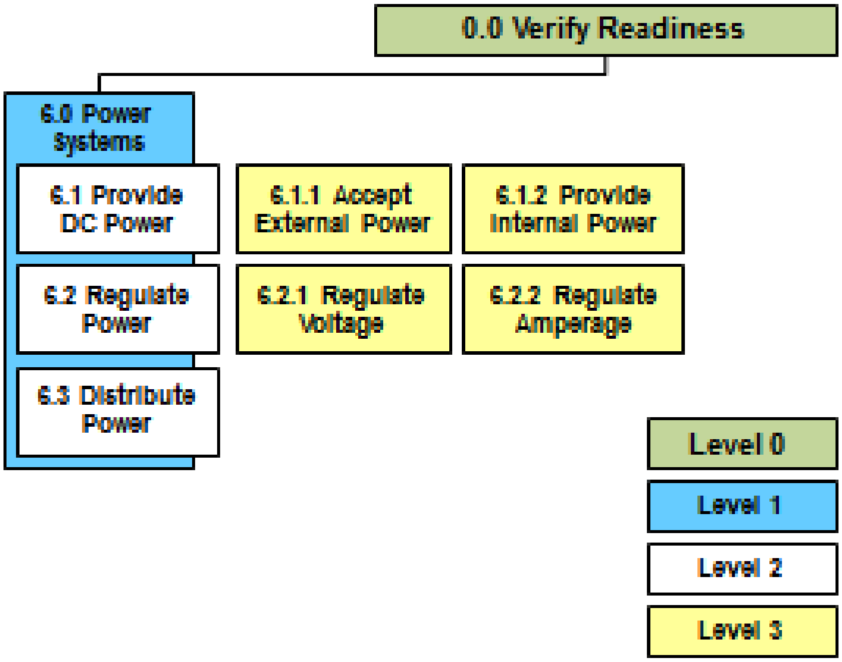

Figure 13. Detailed Decomposition of (6.0) Power Systems Functions

Provide DC Power: This function describes the requirement that all subsystems be provided stable DC power throughout all phases of operation. The subfunction (6.1.1) Accept External Power, describes the requirement that the STM be capable of receiving power from an external source, such as via Mk 41 VLS umbilical connection. This would be the primary power source during pre-flight to prevent premature battery depletion. The subfunction (6.1.2), Provide Internal Power, describes the requirement that the STM have an onboard power source capable of providing power to all onboard subsystems for the duration of flight operations.

Regulate Power: This function describes the requirement that power from any source be regulated to prevent damage to subsystem components. The subfunction (6.2.1), Regulate Voltage, describes the requirement that onboard voltage be regulated to provide the proper voltage to subsystem components. This may require either stepping-up or stepping-down of the power source's supply voltage. Implied in this requirement are output voltage stability and elimination of ripple voltage from the power source, as well as potentially some level of EMI filtering. The subfunction (6.2.2), Regulate Amperage, describes the requirement that current supplied by the power source be regulated.

Distribute Power: This function describes the requirement that power be distributed throughout the STM to all subsystems. No further decomposition of this particular function is required.

B. FUNCTIONAL ALLOCATION

The functional allocation, or form-to-function mapping, attempts to describe how a system performs its various required functionality. The functions of a missile are already fairly well established, so for brevity's sake, this section will cover only those functions which present the greatest risk or possess the most novelty in terms of mission design. A full functional allocation, complete with morphological analysis and value assessment, is out of scope of this report due to the highly conceptual nature of the proposed alternative. Despite this, various materiel alternatives for the novel functions performed by the concept will be discussed to assess feasibility and to aid in further analysis.

1. Novel Function Allocation

The most novel of the functions to be accomplished primarily revolve around the STM's recovery capability. In addition to this, the lack of a warhead presents a challenge to completing the Command Destruct function. Various novel functions identified in the preceding decomposition are listed in Table 3. These functions are each provided with multiple materiel alternatives for consideration. This list is not intended to be exhaustive, but rather to assist in identifying the tradespace and design decisions that will need to be considered to bring the STM concept to fruition.

FUNCTION	MATERIEL SOLUTION ALTERNATIVES
1.5 Interface with Recovery System	
1.5.1 Provide Lifting Points	Recessed lugs, Reinforced sections
1.5.2 Provide Securing Points	Reinforced Sections, bands or straps, threaded holes
4.1 Survive Water Entry	
4.1.1 Stabilize Airframe	Drogue, airbrake, control surface orientation
4.1.2 Decelerate Airframe	Climb-out, parachute (single or multiple canopy)
4.1.3 Withstand Impact	Reinforced airframe, shock-hardened electronics enclosure, reinforced control surfaces
4.2 Transmit Location	
4.2.1 Transmit Location Visually	Strobe light, dye marker, smoke generator, reflective paint
4.2.2 Transmit Location via RF	MOBI-type transmitter, HF beacon, miniturized AIS transponder
4.3 Maintain Buoyancy	
4.3.1 Provide Buoyant Force	Inherent design buoyancy, air trapping, airbag system
4.3.2 Maintain Watertight Integrity	Resilient seals and/or gaskets
4.3.3 Maintain Proper Attitude	Design consideration for center of buoyancy
5.3 Comply with Command Destruct	
5.3.2 Terminate Flight	Explosive charge, maneuver, rocket motor jettison

Table 3. Materiel Solution Alternatives for Selected Functions

a. Interface with Recovery System

The Recovery System for the STM is envisioned as being flexible and adaptable to various means of recovery. In order for the airframe to be recovered post-flight, allocations must be made for the lifting of the airframe from the water by helicopter or crane. The simplest way to accomplish this would be to have recessed lugs that would allow the attachment of eye bolts or other implements to allow the airframe to be easily attached to a lifting device. In addition, the airframe must be reinforced near these lugs to prevent damage as the weight of the airframe is transferred onto the lugs. The Provide Securing Points function would require consideration of the means of transport. Ideally, the airframe would be placed and then secured via any manner of means to some form of cradle.

Once secured in the cradle, access to the interior of the airframe and electronic components within for inspection, test, or data extraction must be accomplished. To permit this, again, the design of the cradle must be considered, and access panel placement informed by the chosen design so no physical interference occurs. The means of panel access must also be considered. For example, tool-less access would be ideal for rapid access while in the field, but the cost-benefit of such schemes would have to be considered.

b. Survive Water Entry

The survival of the missile over multiple launch and recovery cycles is a key function in driving down the cost per firing. To accomplish this function, the airframe must first be stabilized, then slowed to an acceptable rate of descent prior to water entry. Stabilizing the missile after fuel exhaustion could be accomplished by deploying a drogue, or by reconfiguring the control surfaces to provide a stabilizing force. Deceleration would best be accomplished by a variety of means due to the high velocity of the airframe. Assuming fuel exhaustion at the intercept point, a climb-out would allow the airspeed to bleed off and allow for safe deployment of a parachute or parachutes. Because the airframe will impact the water with some velocity, it is also important to consider the design of the onboard electronics. They should be configured in a shock-tolerant mounting to withstand both launch and impact forces. Additionally, the airframe itself and the control surfaces should be robust enough to withstand the force of water impact.

c. Transmit Location

To facilitate rapid recovery, the firing unit or designated recovery unit must be capable of rapidly locating the STM airframe after each firing event. Multiple effective means exist. To visually determine the location of the airframe, a variety of means could potentially be employed, from a salt water-activated strobe light, to dye markers that deploy on impact, to reflective paint or tape on the airframe itself. Electronically locating the airframe would be helpful in the initial search phase, and means employed to accomplish this would include the use of a MOBI-type transponder, a simple HF beacon that would allow for direction finding, or even a miniaturized AIS transponder that would transmit the precise GPS location of the airframe.

d. Maintain Buoyancy

To permit the recovery of the airframe post-flight, it is imperative that the airframe maintain buoyancy such that it remains at the surface of the water. To do so, some buoyant force must be present. This could be provided by inherent design buoyancy—the use of lightweight materials, air-tight compartments filled with some buoyant material, or even an airbag system that inflates upon impact with the water. Alternatively, or in conjunction with other methods, the entrapment of air within the solid rocket motor casing could be accomplished by designing the airframe to enter the water with the rocket motor facing downward, similar to the Space Shuttle's solid rocket boosters.[17]

Once in the water, buoyancy must be maintained for some duration to allow the firing unit or designated recovery unit time to locate and recover the airframe. To ensure this, and to prevent damage to sensitive electronic components, all accesses to areas of the interior of the airframe that contain electronics or are buoyant compartments must be sealed. Gasket materials would have to be resilient to the effects of aerodynamic heating and exposure to salt water. Additionally, RF windows or airframe-mounted antennas would have to be both watertight and impervious to salt water.

Finally, the attitude that the airframe assumes in the water must be conducive to rapid and safe recovery. Accomplishing this requires that the placement of buoyant compartments or external apparatuses must be deliberate, such that the sum of provided buoyant forces maintains the airframe in a desired orientation once in the water.

e. Comply with Command Destruct

With no warhead, compliance with ordered self-destruction is not as straightforward as it would be with a conventional missile. One option to enable this would be to place a small charge at the base of the solid rocket motor, such that when triggered, the solid rocket motor's remaining fuel is detonated. This, however, would likely leave much of the airframe intact, and traveling in the same relative direction.

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[17] "Solid Rocket Boosters," *NASA*, last modified August 31, 2000, http://science.ksc.nasa.gov/shuttle/technology/sts-newsref/srb.html

Another option would be for the missile to pitch steeply downward and impact the water. Again, the results would be unpredictable, as the rocket motor could survive impact and continue to burn, propelling the missile through the water or causing porpoising. Another potential way to terminate flight would be to separate the rocket motor from the airframe through some means. This would cause unpredictable trajectories for both the rocket motor and the airframe, however. Ultimately, the decision for which method of flight termination to use will be contingent on testing various methods to ensure they do not compromise the safety of the round for use in a fleet environment.

f. Avoid Target

Unlike a Standard Missile or ESSM operating with a WCT installed, there is no need to drive the STM and target into close range with one another. With no Target Detection Device (TDD) on the STM, the amount of data to be gathered by such a close encounter is minimal at best, and outweighed by the potential cost of a collision with the target drone and loss of both the drone and the STM. Numerous ways exist to prevent or minimize the risk of collision. The most straightforward would be altitude deconfliction, where the minimum altitude of the STM is set to be some distance above the programmed flight altitude of the target drone. Another means would be through the use of a transmitter on the target drone. Transmitting at fixed amplitude, a receiver on the STM could judge its distance from the target and evade by pitching upward as required. Another would be to set a threshold of amplitude for the received reflected RF from the CWI system. Excursions above a set amplitude threshold would prompt the STM to pitch upward to avoid collision.

2. Canister Alternatives

Depending on its configuration, a STM may or may not require a dedicated canister. All Aegis-configured STMs, however, will require a canister, so a discussion of alternatives is prudent. Assuming the STM is designed with a 10-inch airframe diameter, only two extant canister options are available. This diameter would put it in the same size class as the NSSM, ESSM, and Patriot PAC-3 missile and thus maximize its adaptability to various launchers, and thus should be considered a design requirement. The two canister options are therefore the Mk 22 and the Mk 25. The Mk 22 canister is designed to allow the use of RIM-7 NSSM rounds with the Mk 41 VLS, while the Mk 25 is a quad-pack designed to adapt the RIM-162 ESSM to Mk 41 VLS.[18]

One option would thus be to utilize the quad-pack loaded with one STM and three ESSMs. The advantage to this would lie in the fact that ships would have a STM ready at hand for testing or training purposes. There would be no need to return to port to load a STM specifically to conduct a training shot. The disadvantages would be that there would be a danger that the STM could be expended against an actual target, there would be a reduction in the number of defensive missiles carried, and if fired, the canister would possibly need to remain on the ship for an extended amount of time before being returned for overhaul. The use of the Mk 22 canister would require loading followed by a post-firing offload, but this would help make the STM firing a discrete event and would not require ships to deploy with one cell wasted on a test missile. Being able to remove the canister and rapidly recondition it is key in preventing oxidative corrosion caused by missile exhaust residue, as noted in Chapter III. A third option would be to repurpose Mk 13 canisters as the SM-2 inventory declines. This would provide canisters at essentially no cost, although they would require significant modification of their launch rail to accept a 10-inch diameter missile among other things, adding an unknown cost.

C. SUMMARY

The analysis presented here decomposed the various functions required for successful development and implementation of a STM, and began the process of mapping form to function. Six top-level functions were identified and decomposed into subordinate functions, these were; manage interfaces, control flight, record data, ensure recovery, minimize risk, and provide power. Further study and review by engineers of the applicable disciplines will ensure the validity of the functions described here, as well as their applicability to a specific configuration of STM. Having analyzed the functions necessary for safe and effective operation of the STM, the next step is to determine requirements for the system.

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[18] "VLS Mk 41 Canisters," BAE Systems Land And Armaments, accessed April 14, 2014, http://www.baesystems.com/download/BAES_046051/vls-mk-41-missile

V. REQUIREMENTS PLANNING

Drawing from the proposed concept of operations and the functions decomposed for the STM, a list of formalized requirements can be generated. These requirements dictate the threshold and goal performance for a variety of operational performance measures. Due to the highly conceptual nature of this report, a full functionally-derived requirements list is not developed. This chapter instead examines the critical operational issues (COI) that contribute to the feasibility and efficacy of the STM, and put in place measures of effectiveness and measures of performance from which to consider detailed system-level requirements. High-level requirements that affect design decisions are discussed, as well as means to verify their performance.

A. CRITICAL OPERATIONAL ISSUES

When holistically considering the STM concept, it becomes obvious that there are a number of issues that could derail the proposed concept of operations as well as the potential cost advantages of the concept if not addressed early in the Systems Engineering process. These issues were explored with the various technical stakeholders, and are here broken down and examined in detail.

As depicted in Table 4, five critical operational issues were identified as challenges to the successful development and cost-effective fielding of the STM concept. These issues are explored in a more detailed fashion by identifying measures of effectiveness and, in some cases, the measures of performance that relate to them.

Critical Operational Issues	COI Description
SURVIVABILITY	Can the STM be made to survive multiple flights? Will the recovery system work as envisioned? Will target collisions be avoidable?
SAFETY	Will the STM be safe to operate within a fleet environment? Is the STM safe to recover and transport?
INTEROPERABILITY	Can the STM be made compatible with multiple, disparate Combat Systems?
EFFECTIVENESS	Is an STM firing event an effective test of installed Combat Systems? Is the training provided by a STM launch effective?
MAINTAINABILITY	How expeditious and expensive is it to overhaul the STM and its canister post-flight?

Table 4. Critical Operational Issues identified for the Surrogate Test Missile Concept.

1. Survivability

The survivability of the reusable STM concept is a key consideration. The reusability of the round after each flight is critical to offset the initial acquisition cost and to drive the cost-per-flight figure downward, as is explored in detail in the next chapter. How then to gauge the survivability of such a round? As shown in Table 5, three key considerations are the STM's ability to survive all phases of multiple flights, the overall ruggedness of the airframe and its components, the proper functioning of all components of the recovery system, and the ability of the STM to avoid collision with that target. Other considerations that could affect the survivability of the round include the reliability of the flight control electronics and the reliability of the control surface actuators.

To develop MOEs for survivability, the individual questions of the Critical Operational Issue are broken into component parts with a MOE assigned to each. These MOEs are further broken into component Measures of Performance.

COI	Objective	Measures Of Effectiveness
SURVIVABILITY	Airframe Lifespan	Average number of flights per airframe
		Number of serious defects/Number of flight events
	Effectivness of Recovery System	Average time required to locate airframe post-flight
		Average time to recover airframe
		Number of successful recoveries/Number of flights
	Collision Avoidance	Number of target Collisions/Number of flights

Table 5. Survivability COI, Objectives, and Measures of Effectiveness.

As is illustrated in Table 5, the survivability COI breaks down into multiple objectives and Measures of Effectiveness, which will be further broken down into Measures of Performance. These measures can be used as a basis for validating and verifying system and component-level requirements during both developmental and operational test and evaluation. The MOEs identified in Table 5 are next broken down further into MOPs, as shown in Table 6.

Objective	Measures Of Effectiveness	Measures Of Performance
Airframe Lifespan	Average number of flights per airframe	Number of successful flights
	Number of serious defects/Number of flight events	Number of serious defects discovered during inspection
		Number of flights flown by affected airframe
Effectiveness of Recovery System	Average time required to locate airframe post-flight	Time required to acquire RF beacon
		Time required to visually acquire airframe
	Average time to recover airframe	Time required to recover airframe via helo
		Time required to recover airframe via RHIB
		Time required for SAR swimmer to rig airframe for lift/tow
	Number of successful recoveries/Number of flights	Overall number of successful recoveries
		Overall number of flight events
Collision Avoidance	Number of target Collisions/Number of flights	Overall number of target collisions
		Overall number of flight events

Table 6. Survivability Objectives and Measures of Effectiveness and Performance.

Each MOP identified in Table 6 contributes a verifiable data point for tracking throughout the concept's developmental test and evaluation and into its operational life cycle. These MOPs are not all inclusive, but represent an attempt to begin to frame the requirements within the context of functional solutions.

a. Airframe Lifespan

This objective evaluates the lifespan of an in-service STM round. This objective is judged as a function of two MOEs. The first, Average number of flights per airframe, evaluates the number of flights each STM has performed successfully. As STMs are repeatedly expended during live-fire testing, the number of flights per airframe will be tracked by serial number. Upon retirement, the number of flights at retirement will be noted. By tracking these figures, an estimated lifespan can be calculated for future STM rounds. The next, Number of Serious Defects/Number of Flight Events, tracks the ratio of service-ending defect discoveries to the number of flights flown. A large number here could indicate reliability or manufacturing defects that are limiting the number of flights each round can safely perform, or highlight areas that require further engineering.

b. Effectiveness of Recovery System

This objective is focused on the overall performance of the Recovery subsystems onboard the STM. There are three MOEs that assess the effectiveness of the recovery system. The first, Average time required to locate airframe post-flight, evaluates the performance of the locating devices, visual or electronic, onboard the STM. The next, Average time to recover airframe, aids in determining the performance characteristics of the various subsystems designed to facilitate the recovery and transport of the STM to the firing unit or designated recovery unit. The final MOP, Number of successful recoveries/Number of flights, evaluates the holistic performance of the location and recovery subsystems. Ideally, this figure would remain close to one, if the number were to grow significantly smaller, it could indicate a problem with subsystems or procedures.

c. Collision Avoidance

This objective evaluates the performance of the selected collision avoidance system or procedures. Its sole MOE, the ratio of the number of target collisions to the total number of flights, evaluates the likelihood of a target collision for any given flight. This MOE will evaluate whether the chosen alternative is effective at preventing collisions between the STM airframe and the target drone. Any event resulting in collision will be cause for investigation.

2. Safety

In order to feasibly use the STM in a fleet environment, it must be proven safe in all phases of flight. Pre-flight, it must be stable and provide firebreaks when installed in VLS. It must be identifiable as a test missile both visually and electronically. In flight, it must be controllable. Post-flight, it must be able to be recovered without posing undue risk to recovery personnel.

COI	Objective	Measures Of Effectiveness
SAFETY	Safe VLS Operation	Average maximum temperature of adjacent cells during restrained firing
		Restrained firing or misfire/Number of attempted launches
	Safe Flight Performance	Average deviation from programmed min/max altitude
		Departures from expected flight path/Number of flights
		Percentage of successful command destruct signals
	Recovery Safety	Average amount of time required to recover airframe
		Percentage of successful recovery attempts

Table 7. Safety COI, Objectives, and Measures of Effectiveness

The Safety COI is decomposed into three Objectives and seven Measures of Effectiveness in Table 7. While, again, not all inclusive, these objectives and MOEs set verifiable expectations for both test and evaluation as well as for operational performance. Critical objectives are determined to be Safe VLS Operation, Safe Flight Performance, and Recovery Safety. There is some overlap in MOEs between safety and survivability in the Recovery Safety objective, as a key element of both safety and long-term survivability is the time required to recover the airframe post-flight. The identified MOEs are next further broken out into MOPs.

Objective	Measures Of Effectiveness	Measures Of Performance
Safe VLS Operation	Average maximum temperature of adjacent cells during restrained firing	Maximum temperature recorded in each adjacent cell during restrained firing
	Restrained firing or misfire/Number of attempted launches	Number of restrained firing events
		Number of misfires
		Overall number of attempted launches
Safe Flight Performance	Average deviation from programmed min/max altitude	Maximum recorded deviation from programmed minimum altitude
		Maximum recorded deviation from programmed maximum altitude
	Departures from expected flight path/Number of flights	Overall number of departures from flight path
		Overall number of flight events
	Percentage of successful command destruct signals	Overall number of ordered command destruct events
		Overall number of expected flight terminations
Recovery Safety	Average amount of time required to recover airframe	Time required to recover airframe via helo
		Time required to recover airframe via RHIB
		Time required for SAR swimmer to rig airframe for lift/tow
	Percentage of successful recovery attempts	Overall number of recovery attempts
		Overall number of successful recovery attempts

Table 8. Safety Objectives and Measures of Effectiveness and Performance

The breakdown of MOEs into component MOPs in Table 8 is, again, not exhaustive. Further evaluation would be required based on design decisions prior to the commencement of DT&E.

a. Safe VLS Operation

This objective is primarily concerned with gauging the risk these rounds pose to the firing unit through their interface with the Mk 41 VLS. One key consideration is the ability of the canister to protect adjacent cells from the potential for heat damage in the event of a restrained firing. High temperatures could be indicative of failure of interface with the deluge or gas management system. Another is the restrained fire or misfire rate of the STM. Problems here could indicate issues with rocket motor arming circuits, launch rail design, hold-down bolts, and other hardware or electronic design issues.

b. Safe Flight Performance

Any missile flight operation is inherently hazardous, so assessing the controlled flight of the STM is a critical consideration for safety. The first Measure of Effectiveness assesses the STM's ability to maintain programmed altitude limits. Issues with maintaining altitude could cause the missile to impact the sea surface, the target drone, or leave the dogbox put in place for the missile flight. All are potential hazards. Problems with maintaining altitude could stem from hardware or software issues. The next MOE is concerned with the STM's ability to maintain controlled flight downrange. Deviations in flight path are potentially hazardous, even if they do not violate altitude limits. If observed, these deviations could signal issues with flight control hardware or software. Finally, the STM's ability to terminate its flight is key to reducing the hazards such a round would represent, especially in a fleet firing environment with multiple ships.

c. Recovery Safety

The ability to be recovered safely is critical to achieving the goal of a truly reusable round. MOEs include the time required to recover the round and the percentage of recovery attempts that are successful. The time required to recover the round impacts the safety of the personnel involved in the recovery attempt, specifically the boat and/or helicopter crews and the SAR swimmer. The percentage of successful recovery attempts is similar in that the underlying assumption is the more attempts required to recover the airframe, the longer duration of time recovery crew will be required to be engaged in recovery operations.

3. Interoperability

While the STM may initially be developed for only one specific combat system, by designing flexibility into the onboard software and hardware, the STM could conceivably emulate any number of missile systems. This, in turn, would increase the acquisition quantity and derive some cost benefit from doing so. The MOEs identified based on the Interoperability objective are illustrated in Table 9.

COI	Objective	Measures Of Effectiveness
INTEROPERABILITY	Combat Systems Compatibility	Number of Combat Systems STM is compatible with
		Average number of modifications required to achieve compatibility

Table 9. Interoperability COI, Objective, and Measures of Effectiveness

a. Combat Systems Compatibility

As shown in Table 9, Interoperability will be assessed primarily as a function of how many systems the STM can be made compatible with, through either software or hardware modification. The number of modifications required to permit the compatibility would be an important cost driver in making cross-platform interoperability feasible, and is thus the second MOE.

4. Effectiveness

The effectiveness of the STM will primarily be a function of its ability to verify the readiness of the firing unit’s installed combat system and the training its use provides to key watchstanders. The ability to verify the readiness of the combat system for the Aegis-specific STM is a function of its ability to test the VLS interconnections, which must function for the missile to receive the launch command, and once launched, its ability to receive and measure radiation from the AN/SPY-1 radar and AN/SPG-62 illuminator. The training effectiveness of the round is a function of its ability to emulate the specific missile it is simulating as well as how the firing scenario is framed and conducted by the firing unit. The breakdown of various related objectives into MOEs is depicted in Table 10.

COI	Objective	Measures Of Effectiveness
EFFECTIVENESS	Training Effectiveness and Realism	Additional training opportunities allowed by STM
		Reported training fidelity and satisfaction
	Readiness Verification Effectiveness	Percentage of critical CS functions verified by STM
		Average number of deficiencies detected/corrected during pre-fire maintenance
		Average number of deficiencies detected by STM
		Average number of deficiencies detected/corrected during post-fire maintenance

Table 10. Effectiveness COI, Objectives, and Measures of Effectiveness

a. Training Effectiveness and Realism

To assess the effectiveness and realism of the training conducted using the STM is a difficult task. One metric that can be used is a simple analysis of that number of additional firing opportunities granted through the STM's reduced cost and range requirements. Another is the reported fidelity and satisfaction of watchstanders on firing units. Ideally, Afloat Training Groups and Tactical Training Groups would be leveraged to provide baseline training scenarios and metrics for diverse firing units so that there is uniformity in the use of the STM.

b. Readiness Verification Effectiveness

The effectiveness of the STM's ability to verify the operability of the firing unit's combat systems suite is measured through four MOEs. The first is the percentage of critical combat systems functions verified by the STM. This will vary between different systems if the STM concept is expanded to different combat systems. The delta between the percentage that are able to be tested synthetically and the percentage tested by the STM is one measure of the benefits provided by the STM concept. The next three are a function of the faults or deficiencies found or corrected during any phase of an STM firing event. The ability to detect, isolate, and correct faults prior to entering combat is a key readiness challenge, and these MOEs evaluate the STMs ability to do just that.

5. Maintainability

The maintainability COI assesses the overhaul portion of the STM life cycle. The primary objective is to minimize the time and complexity involved in any overhaul, which in turn is expected to drive the cost per firing cycle down. As such, the MOEs associated with this objective concern the man-hours being expended on various aspects of the overhaul, as well as parts required and the quality assurance aspects of the process.

COI	Objective	Measures Of Effectiveness
MAINTAINABILITY	Minimize Overhaul Time and Complexity	Average number of manhours expended on airframe inspection
		Average number of manhours expended on airframe overhaul
		Average number of manhours expended on canister overhaul
		Average number of parts requiring replacement during overhaul
		Average number of STMs failing post-overhaul inspection

Table 11. Maintainability COI, Objective, and Measures of Effectiveness

The maintainability COI is assigned only one objective with five primary measures of effectiveness as shown in Table 11. These assess two of the main cost drivers for the reusable STM concept—the number of man-hours required to conduct inspection and overhaul of STM subsystems and the complexity of that inspection and overhaul.

Objective	Measures Of Effectiveness	Measures Of Performance
Minimize Overhaul Time and Complexity	Average number of manhours expended on airframe inspection	Hours required to complete inspection of airframe
		Personnel required to complete inspection of airframe
	Average number of manhours expended on airframe overhaul	Hours required to complete overhaul of airframe
		Personnel required to complete overhaul of airframe
	Average number of manhours expended on canister overhaul	Hours required to complete overhaul of canister
		Personnel required to complete overhaul of canister
	Average number of parts requiring replacement during overhaul	Number of parts replaced per overhaul
	Average number of STMs failing post-overhaul inspection	Number of STMs failing post-overhaul inspection/total number of overhauls

Table 12. Maintainability Objectives and Measures of Effectiveness and Performance

The measures of performance identified in Table 12 are, again, not all inclusive. The MOPs derived from the Maintainability COI primarily focus on the time and resources required to overhaul the STM. They represent only an initial analysis of the issues associated with the maintainability of the STM and means to verify them.

a. Minimize Overhaul Time and Complexity

Assessing the maintainability of the STM can be accomplished by examining the number of man-hours required to conduct post-flight inspection and overhaul as well as the number of parts required to restore each STM to readiness. These values can be tracked over the lifespan of each STM to assess patterns, or to detect potential design or implementation problems. Excessive man-hour expenditure on certain stages of the overhaul could potentially be rectified through better training, design changes, or component selection changes. Tracking the number of parts being replaced can also serve to provide warnings of design or component selection problems. While it is expected that certain components will need to be replaced after each firing event, for instance the Solid Rocket Motor and perhaps various gaskets and retaining hardware, higher than expected part replacement could signal design problems. Finally, assessing the post-overhaul inspection failure rate will allow program managers to identify problems with procedures and training that could impede the maintainability of the STM.

B. HIGH-LEVEL REQUIREMENTS ASSESSMENT

Drawing from stakeholder input, the concepts of operation, derived functionality, and assessed critical operational issues, the requirements for the concept are next mapped onto specific functions. Due to the conceptual nature of the STM at this stage, a full mapping of requirements to functions will not be performed. Analysis will instead focus on specific high-level and functional requirements that present the greatest challenge to the potential feasibility of the round as envisaged in this report.

1. High Level System Requirements

High-level systems requirements can be drawn from the identified Critical Operational Issues, and attempt to address the underlying questions regarding the system of systems as envisaged. These functions attempt to define the overall operational issues the STM will experience, and to build a framework to assist in the selection of initial design specifications. Again, this report is strictly conceptual, so throughout this section quantitative requirements may not be specifically defined. Any requirement that would typically have a numerical value associated with it will here be simply assigned a value of XX. While non-specific, this will allow for a more thorough analysis to assign more accurate numerical values following an investigation into the trade space and value system of each particular requirement.

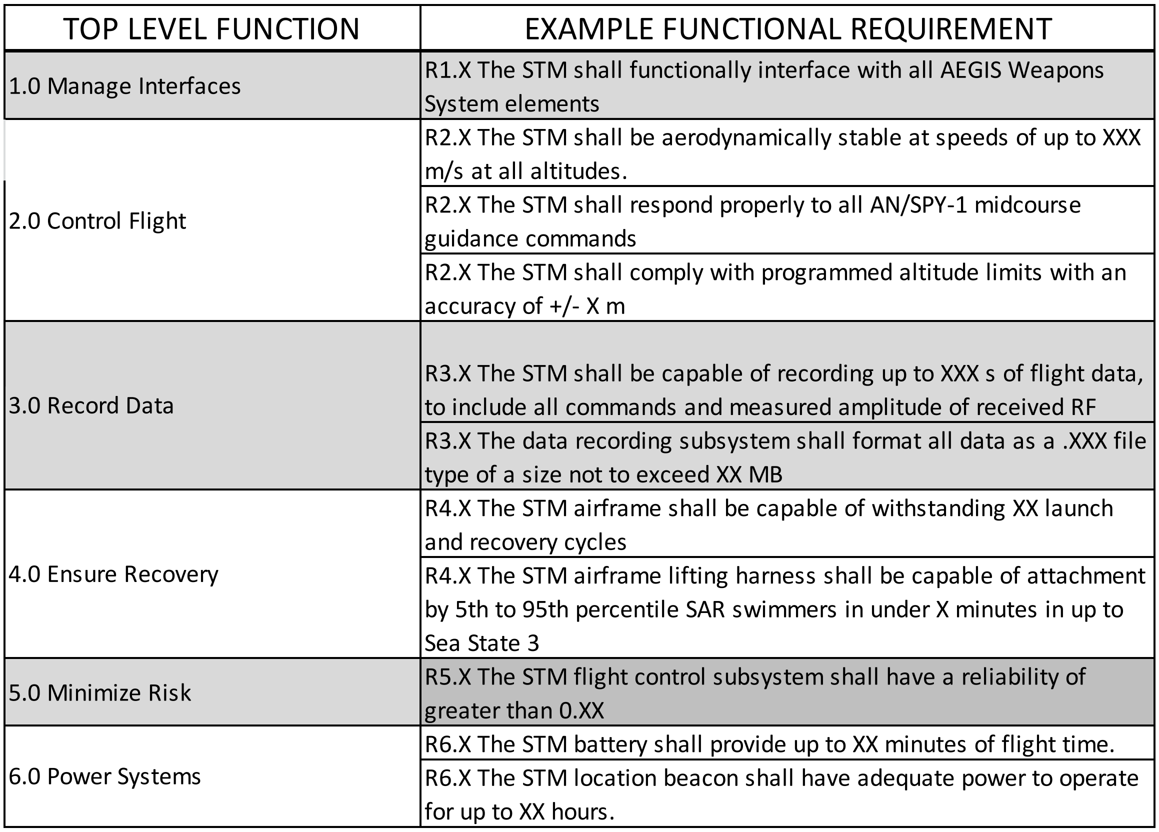
As illustrated in Table 13, even very high level requirements may be useful in making component selection and detailed design decisions. Some of these decisions will include the design and construction of the airframe, where cost and weight will be balanced against the requirement for it to be rugged enough to survive multiple flight cycles. Similarly, the design of the airframe and lift/tow harness will be determined by the requirement that the average SAR swimmer be capable of attaching the harness in a set amount of time.

COI	Example Requirement
SURVIVABILITY	The STM airframe shall be capable of withstanding XX launch/recovery cycles
	The STM recovery system shall function with 0.XX reliability
	The collision avoidance system shall function with 0.XX reliability
SAFETY	The STM canister shall be compatible with VLS deluge and gas management systems.
	The STM rocket motor shall have VLS compatible safety and arming systems installed.
	The flight controls shall function with 0.XX reliability
	The recovery subsystem shall allow 5th to 95th percentile SAR swimmers to attach lift/tow harness within 5 minutes
INTEROPERABILITY	The STM shall be configurable to enable function with other fire control and launch systems.
EFFECTIVENESS	The STM shall test all firing circuits and interlocks of the weapons system during a launch cycle
	The STM shall measure and record amplitude readings of all received RF missile guidance
	The STM shall fullfil XX% of training objectives for a live missile fired for telemetry
MAINTAINABILITY	The STM inspection and overhaul shall require less than XX man-hours to complete
	The STM overhaul shall require no more than XX special tools to complete
	The STM inspection shall require no more than XX items of test equipment to perform

Table 13. High-level System Requirements derived from COIs.

To next decompose top-level functionally-derived requirements for the STM, the functional hierarchy developed in Chapter IV was reviewed.

As demonstrated in Table 14, these functional requirements possess more specificity than their system counterparts. Again, given the early stage of this report, specific values have not been determined.



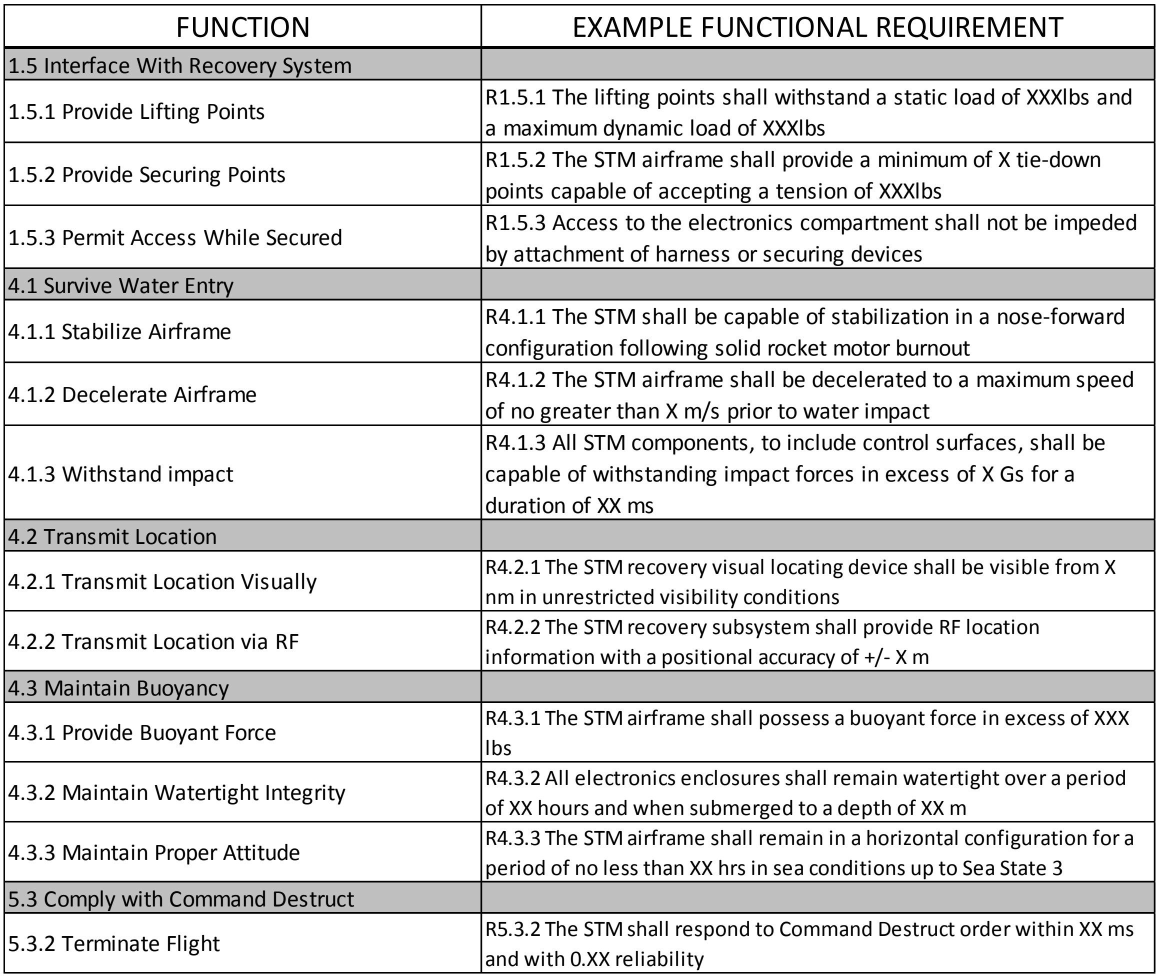
TOP LEVEL FUNCTION	EXAMPLE FUNCTIONAL REQUIREMENT
1.0 Manage Interfaces	R1.X The STM shall functionally interface with all AEGIS Weapons System elements
2.0 Control Flight	R2.X The STM shall be aerodynamically stable at speeds of up to XXX m/s at all altitudes.
	R2.X The STM shall respond properly to all AN/SPY-1 midcourse guidance commands
	R2.X The STM shall comply with programmed altitude limits with an accuracy of +/- X m
3.0 Record Data	R3.X The STM shall be capable of recording up to XXX s of flight data, to include all commands and measured amplitude of received RF
	R3.X The data recording subsystem shall format all data as a .XXX file type of a size not to exceed XX MB
4.0 Ensure Recovery	R4.X The STM airframe shall be capable of withstanding XX launch and recovery cycles
	R4.X The STM airframe lifting harness shall be capable of attachment by 5th to 95th percentile SAR swimmers in under X minutes in up to Sea State 3
5.0 Minimize Risk	R5.X The STM flight control subsystem shall have a reliability of greater than 0.XX
6.0 Power Systems	R6.X The STM battery shall provide up to XX minutes of flight time.
	R6.X The STM location beacon shall have adequate power to operate for up to XX hours.

Table 14. Example Top Level Functional Requirements

2. Functional Requirements

Table 3 in Chapter IV provided a high-level look at possible design alternatives for functions that could be considered novel or high-risk. These functions provide an obvious starting point for the mapping of more detailed functional requirements.

Example functional requirements for novel or high-risk functions are provided in Table 15. Of all the requirements described in this chapter, these are the most specific, and would drive decision makers toward specific choices in either design or component selection.



FUNCTION	EXAMPLE FUNCTIONAL REQUIREMENT
1.5 Interface With Recovery System	
1.5.1 Provide Lifting Points	R1.5.1 The lifting points shall withstand a static load of XXXlbs and a maximum dynamic load of XXXlbs
1.5.2 Provide Securing Points	R1.5.2 The STM airframe shall provide a minimum of X tie-down points capable of accepting a tension of XXXlbs
1.5.3 Permit Access While Secured	R1.5.3 Access to the electronics compartment shall not be impeded by attachment of harness or securing devices
4.1 Survive Water Entry	
4.1.1 Stabilize Airframe	R4.1.1 The STM shall be capable of stabilization in a nose-forward configuration following solid rocket motor burnout
4.1.2 Decelerate Airframe	R4.1.2 The STM airframe shall be decelerated to a maximum speed of no greater than X m/s prior to water impact
4.1.3 Withstand impact	R4.1.3 All STM components, to include control surfaces, shall be capable of withstanding impact forces in excess of X Gs for a duration of XX ms
4.2 Transmit Location	
4.2.1 Transmit Location Visually	R4.2.1 The STM recovery visual locating device shall be visible from X nm in unrestricted visibility conditions
4.2.2 Transmit Location via RF	R4.2.2 The STM recovery subsystem shall provide RF location information with a positional accuracy of +/- X m
4.3 Maintain Buoyancy	
4.3.1 Provide Buoyant Force	R4.3.1 The STM airframe shall possess a buoyant force in excess of XXX lbs
4.3.2 Maintain Watertight Integrity	R4.3.2 All electronics enclosures shall remain watertight over a period of XX hours and when submerged to a depth of XX m
4.3.3 Maintain Proper Attitude	R4.3.3 The STM airframe shall remain in a horizontal configuration for a period of no less than XX hrs in sea conditions up to Sea State 3
5.3 Comply with Command Destruct	
5.3.2 Terminate Flight	R5.3.2 The STM shall respond to Command Destruct order within XX ms and with 0.XX reliability

Table 15. Example Functional Requirements Mapping for Novel Functions.

C. SUMMARY

The analysis in this chapter provided initial analysis into the Critical Operational Issues and the requirements required to be generated for the conceptual STM system-of-systems. Five COIs were determined; survivability, safety, interoperability, effectiveness, and maintainability. The objectives, MOEs, and MOPs derived from these COIs serve as the rough frame for deriving requirements. Analyzing the requirements for such a system helps to frame the tradespace for a future detailed alternatives analysis, which in turn will inform the cost estimation process for such a system. While analysis at this level of detail is beyond the scope of this report, this chapter should provide decision-makers with enough information to approach the problem from a systems engineering perspective and further define the requirements and means to verify them going forward. Based on the analysis in this chapter, as well as the preceding analysis detailing the initial Concept of Operations and the functional decomposition of the STM, an initial cost estimation is possible.

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VI. COST, LIFE CYCLE CONSIDERATIONS, AND POTENTIAL FURTHER APPLICATION

A. STM COST ANALYSIS

Estimating the cost of the STM is critical in determining the benefit the development and fielding of such a round would realize for the Fleet. This is complicated somewhat by the fact that it is a novel solution – no direct analogy currently exists, so assumptions must be made in estimating the cost of research and development (R&D), acquisition, and operations and support.

1. Unique Cost Components of Surrogate Test Missile Program

The development and fielding of the STM will incur costs in multiple, discrete areas. The STM is expected to follow the traditional program life cycle of research, development, test, and evaluation (RDT&E), followed by production, followed by operations and support, and finally ending with disposal. The operations and support phase will have a unique cycle of firing costs followed by overhaul costs, which will briefly be described below. These costs will not be estimated in detail in this report due to their variable nature and the difficulty associated with doing so without a good source of analogous data.

a. Firing Costs

The firing costs for the STM will here be defined as all costs incurred in support of live-fire testing or training conducted using the STM, including;

- Transportation of STM to ship and loading (as required)
- Target Drone launch and recovery (if utilized)
- Recovery Platform costs (if utilized)

Each of these costs depends on a number of factors. The transportation costs will vary based on the ship’s location. For instance, a ship conducting a firing event out of Rota will incur a much higher transportation cost compared with a ship that loads a STM at Naval Weapons Station Yorktown. Target drone costs will vary with the type of drone utilized, the firing range used, and the safe recovery of the drone. Finally, if, for whatever reason, the firing unit is unable to recover the STM unassisted, cost will be incurred in the form of a designated recovery platform.

b. Overhaul Costs

Overhaul costs for the STM will be defined as all costs incurred during the post-firing overhaul and refurbishment of all STM components. These costs include;

- Transportation of STM and canister to overhaul facility
- STM inspection
- STM component replacement
- Canister refurbishment
- STM – Canister mating
- Quality Assurance Tests

Overhaul costs, like firing costs depend on multiple factors, such as the condition of the STM and canister upon arrival at the designated overhaul facility. STMs that have been damaged, either through firing or through improper storage or transportation, will likely take longer to overhaul, or will necessitate a higher degree of component replacement. Similarly, STM canister refurbishment will be dependent on the condition of the canister upon arrival. Prolonged storage following a firing event with missile exhaust residue can cause accelerated canister corrosion and necessitate expensive repair procedures, and thus would have to be avoided whenever possible.[19]

To a greater extent than firing costs, overhaul costs will be influenced by design decisions made during the development of the STM. Designing the round for maintainability, as discussed in Chapter V, will minimize the number of man-hours required to inspect and refurbish the round, and through this reduce the costs associated with the overhaul. Minimization of overhaul costs will reduce the overall Operations and Support costs of the STM, so it is critical that early design work stresses the objectives of maintainability.

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[19] Thomas Callies, Launching Systems Program Manager at BAE Systems, conversation with author, January 15, 2014

2. Acquisition Quantity

The total quantity of STMs acquired will be a key consideration in the estimation of both initial acquisition and follow-on Operations and Support Costs. To determine the required quantity of Aegis-configured STMs required to support the CONOPS developed in Chapter III, the Annual Long-Range Plan for Construction of Naval Vessels for FY 2014 was referred to. When the total number of active large surface combatants in each year is averaged, approximately 89 vessels will be active in the inventory each year between 2014 and 2043[20]. Assuming two STMs are acquired per ship, with the addition of 22 more to be stored in forward areas in support of emergent testing or training, an initial acquisition quantity of 200 rounds is assumed. Under the further assumption that all foreign operators of the Aegis weapons system choose to acquire their own STMs, the 21 foreign Aegis ships would add an additional 42 rounds to the total acquisition quantity[21]. Thus, we assume a total procurement of 242 rounds if only the Aegis-compatible STM is procured.

Another acquisition quantity that must be considered is that of the Solid Rocket Motor. Its replacement will be a key cost driver for the overhaul cost following each firing event. To arrive at an initial acquisition quantity, an assumption will be made that one-third of all ships so equipped will conduct a firing event annually. One-third of the 110 ships described above would mean 37 firing events would occur annually, and thus, 37 rocket motors would be required annually. Over a 30-year program lifespan, this would require 1,110 total rocket motors, again, if only the Aegis-configured STMs are procured.

a. Acquisition Quantity Implications

The overall acquisition quantity described here is extremely small compared to other missile programs. For example, the Standard Missile-6 is projected to

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[20] Office of the Chief of Naval Operations, *Report to Congress on the Annual Long-Range Plan for Construction of Naval Vessels for FY2014* (Washington DC: Office of the Chief of Naval Operations, May 2013), 5

[21] “Where in the World is Aegis?” Lockheed Martin, accessed April 7, 2014, http://www.lockheedmartin.com/us/products/aegis/where-in-the-world-is-aegis.html

have a final acquisition quantity of 1,200 rounds,[22] while over 11,000 units of the Standard Missile-2 were acquired over its lifespan.[23] The relatively small acquisition quantity has several distinct implications for the program and its associated costs. First, learning curve effects on acquisition unit cost will be greatly reduced. This will have the result of increasing the average unit cost for the total production run, as seen below in Figure 14. Secondly, non-recurring costs associated with the production of the STM, such as tooling and systems engineering efforts, would be spread out over fewer units, again increasing the average unit acquisition cost. Higher average unit costs contribute to higher costs per firing event, as shown in detail later in the chapter. The general effects of learning curves on average unit cost are shown in Figure 14.

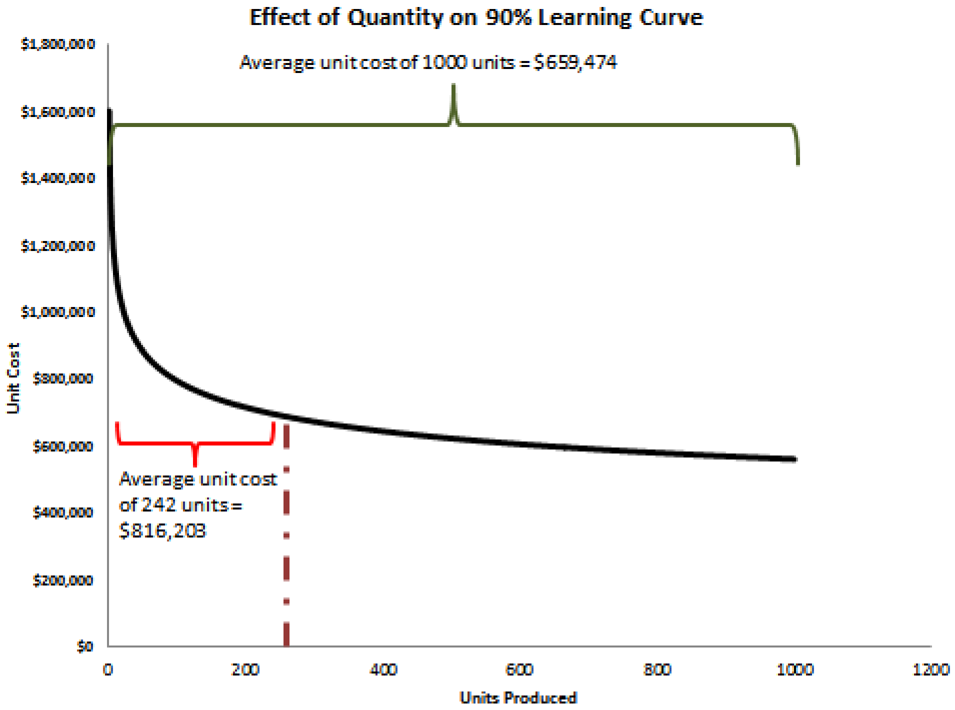

Figure 14. Effect of total unit production on average unit cost assuming T1 of $1,600,000 and 90% learning curve.

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[22] DOD, *Selected Acquisition Report*: *Standard Missile-6*, 20

[23] U.S. Department of the Navy (DON), *FY 2014 President's Budget*; *Justification Book Volume 1; Weapons Procurement, Navy*. (April 2013), 73.

As shown in Figure 14, when examining the learning curve's effect on average unit costs, increasing the quantity from 242 to 1,000 results in average unit costs of roughly 20% less, assuming a conservative 90% learning curve. This was calculated using the equation $Y_X=AX^B$, where Y_X is the cost of unit X, A is the T1, or first unit cost, and B is the slope of the learning curve. The T1 cost was arbitrarily assigned a value of $1,600,000, as this figure is simply to demonstrate the effect of learning curve and quantity on average unit cost. If a steeper learning curve were utilized, for instance 80%, which is not unfathomable for a complex article such as a missile, the cost savings per-unit would increase to closer to 40%.

B. STM COST ESTIMATION

Estimation of the RDT&E and Acquisition costs will be done via the analogy method. The Evolved Sea Sparrow Missile was chosen as the analogous system for multiple reasons. First, it was developed in conjunction with 10 NATO partner countries. As the section on Acquisition Quantity Considerations makes clear, having the widest possible user base to increase the total acquisition quantity will realize tangible cost benefits. Second, like the proposed STM, the ESSM is readily configurable to operate with multiple combat systems, launching systems, and guidance systems.[24] This, again, is critical to expanding the potential user base for the STM, as it would allow the STM to be used on multiple current and future combat systems configurations. Finally, its size and weight are roughly comparable to the size and weight of the STM as currently envisioned. The relevant specifications for the ESSM are described in Table 16.

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[24] "Evolved Sea Sparrow Missile," Raytheon Corporation, accessed April 20, 2014, http://www.raytheon.com/capabilities/products/essm/

Figure 15. Evolved Sea Sparrow Missile launching from Mk 41 VLS.[25]

Length: 12 ft (3.64 m)
Diameter: 10 in (25.4 cm)
Weight: 622 lbs (282 kg)
Speed: Mach 4+
Range: 27+ nm/31+ miles (50+ km)
Guidance System: Raytheon semi-active on continuous wave or interrupted continuous wave illumination
Warhead: Annular blast fragmentation warhead, 90 lbs (40.5 kg)

Table 16. Evolved Sea Sparrow Missile Specifications[26]

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[25] "Evolved Sea Sparrow Missile," Raytheon Corporation, accessed April 21, 2014, http://www.raytheon.com/newsroom/rtnwcm/groups/public/documents/image/rms_rtn_essm_pic04.jpg.

[26] "Evolved Sea Sparrow Missile" Aeroweb, accessed April 27, 2014, https://www.bga-aeroweb.com/Defense/RIM-162-ESSM.html

1. RDT&E Costs

The total U.S. contribution to the ESSM program's RDT&E from its inception to the Full Rate Production decision in 2004 was approximately $382 million. This cost includes Product Development, Support, Test and Evaluation, and Management. This represents a good starting point to estimate the cost of RDT&E for the STM. Of this figure, approximately $169 or 45% of the total RDT&E costs were expended on primary hardware development.[27] For the STM, without a traditional terminal-phase seeker or warhead, it is assumed that costs would be correspondingly lower than a missile with those components. A common heuristic is that seeker costs approximately account for 35% of the cost of missile procurement, while the warhead accounts for approximately 10%.[28] Assuming these costs translate with some approximate accuracy to the hardware development portion of the RDT&E phase, a net savings of 45%, or $93 million dollars would result. This, however, fails to account for the novel technology that would be required to be developed for the STM, such as the various components of recovery system. Due to this, a more conservative assumption is that the primary hardware development of RDT&E would be anywhere from 15 to 25% less expensive. Choosing the midpoint, 20%, gives an estimate of $151 million for the primary hardware development, and a total RDT&E cost of $364 million.

Another area of RDT&E costs in which the unique capabilities of the STM might bear some cost savings would be in the OPEVAL/TECHEVAL/Test Firings category. This accounted for $7 million of the total cost of preparing the ESSM for its full rate production decision.[29] It would be reasonable to assume that using a fully recoverable missile would reduce this expense by at least half, as test vehicles would be recovered after each flight, and thus there would be no need for prototypes that are expended with each test. Obviously, with a traditional missile, every test firing results in the loss of the test vehicle, whereas with the STM the cost would be limited to early stage overhaul

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[27] U.S. Department of the Navy (DON), *FY 2006 Budget Estimates*; *Justification of Estimates; Research, Development, Test, and Evaluation, Navy* (Washington, DC: DON, February 2005). (FY05 to FY14 using JIC Calculator and RDTE index.)

[28] Daniel Nussbaum, e-mail to author, April 22, 2014

[29] DON, *FY 2006 Budget Estimate*s, (FY05 to FY14 using JIC Calculator and RDTE index)

costs and accounting for any failures that may occur. This would reduce the cost of total RDT&E by a further $3.5 million, to approximately $360.5 million.

2. Acquisition Costs

Between the full rate production decision in 2004 and 2010, 388 Aegis-configured ESSMs were acquired at an average unit cost of approximately $795,500. In 2014, an additional 26 were purchased at an average unit cost of approximately $968,000.[30] The reason for the 22% price increase is not given in the source documents, but is likely a combination of a relatively low production rate and a lack of production for a span of four years that would disrupt any incurred learning curve savings. Labor or material price increases could also have played a role. Due to this, only the first 388 will be examined to determine the potential T1 cost of the ESSM. In addition to these 388 Aegis-configured rounds, 222 rounds were purchased for use in the Mk 29 launcher at an average unit cost of $721,878, and a further 18 were produced with X-band terminal guidance capability at an average unit cost of $837,000.[31] As with the Aegis-configured rounds, only those procured prior to FY12 will be examined due to unexplained price increases for both additional variants. Thus, a total of 628 ESSMs were procured through FY12 at an average unit cost of $770,609.

To determine the approximate T1 of Aegis-configured ESSMs, a program was constructed using Microsoft Excel's Solver add-in. The objective function set the average of 628 cells to a value of $770,609. The first cell was set as the variable cell, and the only constraint was the non-negativity of the variable cell. Each cell after the first, variable, cell referenced it via the equation $Y_x=AX^B$, where A was the set as the value of the first cell. For B, a 90 percent learning curve was assumed, as this represents a somewhat conservative value for production of a missile system.[32] Thus, in this formulation, B = LOG(0.9)/LOG(2). When solved using the Simplex LP method, the resulting T1 value was $1,742,913.

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[30] DON, *FY 2014 President's Budget,* 142.

[31] Ibid.

[32] Daniel Nussbaum, conversation with author, April 22, 2014

Using this value, it is possible to make assumptions regarding the approximate cost of the T1 for the STM, and from that estimate an average cost for any number of STM acquisitions. Using the heuristic used in section 1, it can be assumed that the TDD and the warhead together account for approximately 45% of this cost. Again, allowing for the cost of the recovery subsystems, but assuming that they will be less expensive that construct than either the TDD or the warhead once design work is finalized, a conservative estimate of 30% reduction in cost seems reasonable. Thus, our estimate for the T1 cost for the STM is $1,220,039. Assuming a 90% learning curve, the average unit production cost of 242 STMs is about $622,374, whereas an acquisition quantity of 1000 or more has an average unit production cost of about $502,865.

In addition to the round itself, the canister must be considered if the STM is to be used for Aegis ships configured with the Mk 41 VLS. As discussed in Chapter IV, various alternatives are available, and cost will depend on the selected alternative. Further complicating matters, existing canisters may require significant modification both to improve their maintainability and to adapt them to use with the STM. That said, it is possible to provide a rough estimate of the approximate cost per canister. When last acquired in 2011, Mk 13 canisters cost approximately $109,000 per unit in FY11 dollars. This cost was likely inflated due to the fact that only 8 canisters were acquired in that year, resulting in a low production rate price penalty.[33] Nevertheless, an approximate average unit cost of $100,000, assuming an acquisition quantity of greater than 242 and limited modification requirements, seems reasonable to use going forward. Non-Aegis configured STMs used, for example, to emulate an ESSM and fired from a Mk 29 launcher, would not incur this cost.

a. Program Acquisition Unit Cost

Folding in the cost of RDT&E as well as that of acquisition of the STM and its canister, an approximate programmatic unit cost can be estimated. The same 90% learning curve and T1 of $1,220,039 are assumed. The cost of each unit is increased by

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[33] U.S. Department of the Navy, *FY 2013 President's Budget*; *Justification Book Volume 1; Weapons Procurement, Navy*. (Washington, DC: DON, February 2012), 61

$100,000 to account for the cost of the canister. Finally, the total estimated cost of RDT&E, $360.5 million, was added in, then divided by the total number of units acquired to arrive at the estimated PAUC.

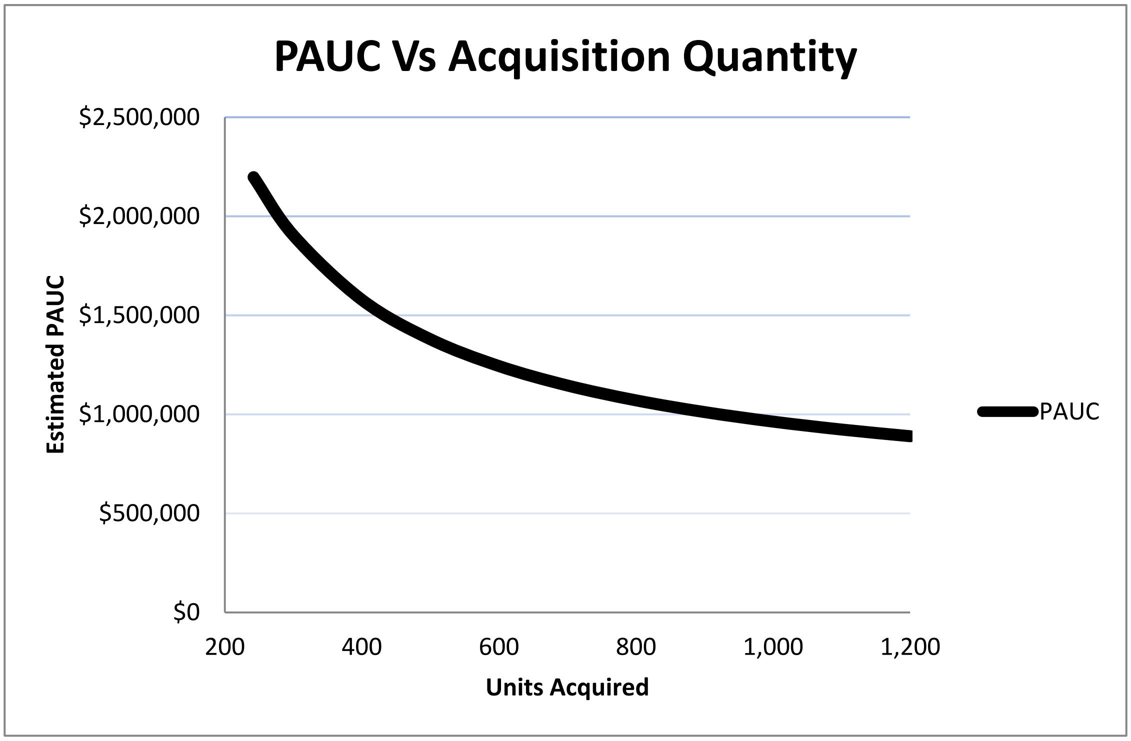

Figure 16. Estimated STM Program Acquisition Unit Costs

Figure 16 shows that at the minimum quantity of 242 assumed for an Aegis-only configuration, the PAUC is approximately $2,212,000. This cost declines rapidly as additional units are purchased, reaching a PAUC of less than $1,000,000 at a total acquisition quantity of roughly 900 total units. At 1200 total units, the PAUC decreases to only $890,000.

3. Operations and Support Cost Estimation

As mentioned in Section 1, the O&S costs of the STM consist of both Firing and Overhaul costs. Both are highly variable, and have numerous cost components. To assist in estimating O&S costs of the STM, only the overhaul costs will be considered, and these costs will be divided into three major cost elements. These are Solid Rocket Motor replacement, canister overhaul, and maintenance. Each of these costs will be incurred each and every time an STM is fired, and the total annual cost will be dependent on the number of firing events conducted that year. Other costs will be incurred, such as transportation and losses due to attrition or failure, but those will be deferred to a more comprehensive cost estimate.

The replacement of the Solid Rocket Motor is expected to be the most expensive single replacement item for the overhaul of the STM itself. All other components would be designed to have a lifespan of multiple flights, but the motor itself would need replacement. To estimate the cost incurred, one of the most likely vendors, ATK Inc, was contacted. Their estimate is approximately $25,000 to $40,000, depending on the quantity acquired and the production rate, for a 10-inch diameter rocket motor with similar specifications to that used on the ESSM or NSSM, both of which are manufactured by ATK.[34] For the purposes of this thesis, the midpoint of these estimates will be used, a cost of approximately $32,500 for each motor.

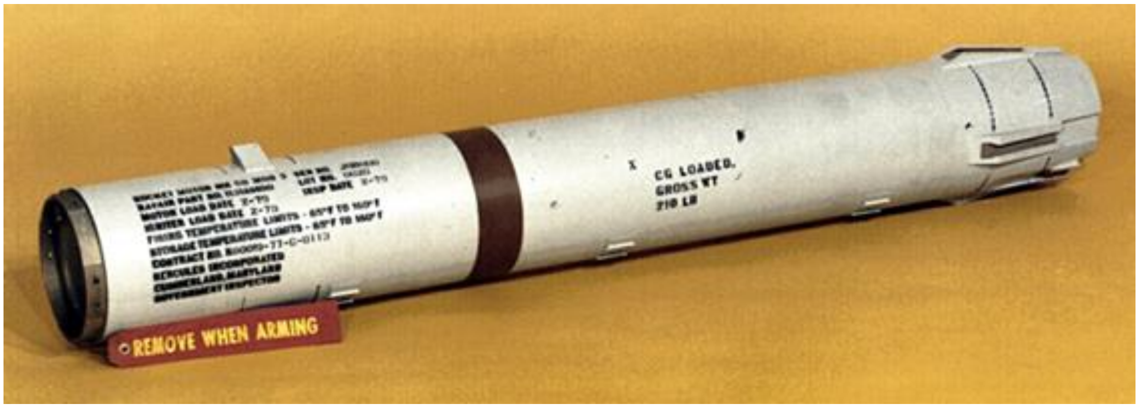

Figure 17. Mk 58 Solid Rocket Motor for NSSM[35]

The next major cost factor is the overhaul/reconditioning of the launch canister. Again, the contractor likely to be responsible for the overhaul, BAE Systems Land and Armaments Division, was contacted for an estimated cost. The cost of overhauling used

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[34] James Agosti, e-mail to author, August 22, 2013.

[35] Ibi.d

Mk 13 canisters runs between $30,000 and $50,000, and is highly dependent on the condition of the canister when received.[36] For the purposes of this thesis, it is assumed that the canister overhaul will be streamlined such that the canister is rapidly transported to the overhaul facility, and thus the lowest cost in the range, $30,000, is incurred.

Finally, the cost associated with each STM overhaul maintenance event is considered. This would consist of the cost to inspect, overhaul, mate the STM with the overhauled canister, and conduct final QA checks prior to shipment. As such, it is the hardest cost to estimate. Additionally, whether this maintenance is performed on contract or by Navy personnel will have major cost implications in terms of manpower costs. As a rough estimate, a cost of $20,000 will be assumed. This would include labor, special tools or equipment used in inspection and overhaul, part replacement, and overhead for the facility utilized for the overhaul. This brings the total estimated cost for an overhaul to $82,500.

4. Cost Per Flight

Unlike a traditional missile, the cost to fire the STM is not simply its acquisition cost. It is the acquisition cost, plus the overhaul cost for each flight, divided by the total number of flights. The PAUC is used as the acquisition cost, and the figure of $82,500 was used for the overhaul cost. The PAUC was varied for different acquisition quantity scenarios. The calculated average cost per flight is displayed as a curve in Figures 18, 19, and 20.

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[36] Thomas Callies, conversation with author, January 15, 2014.

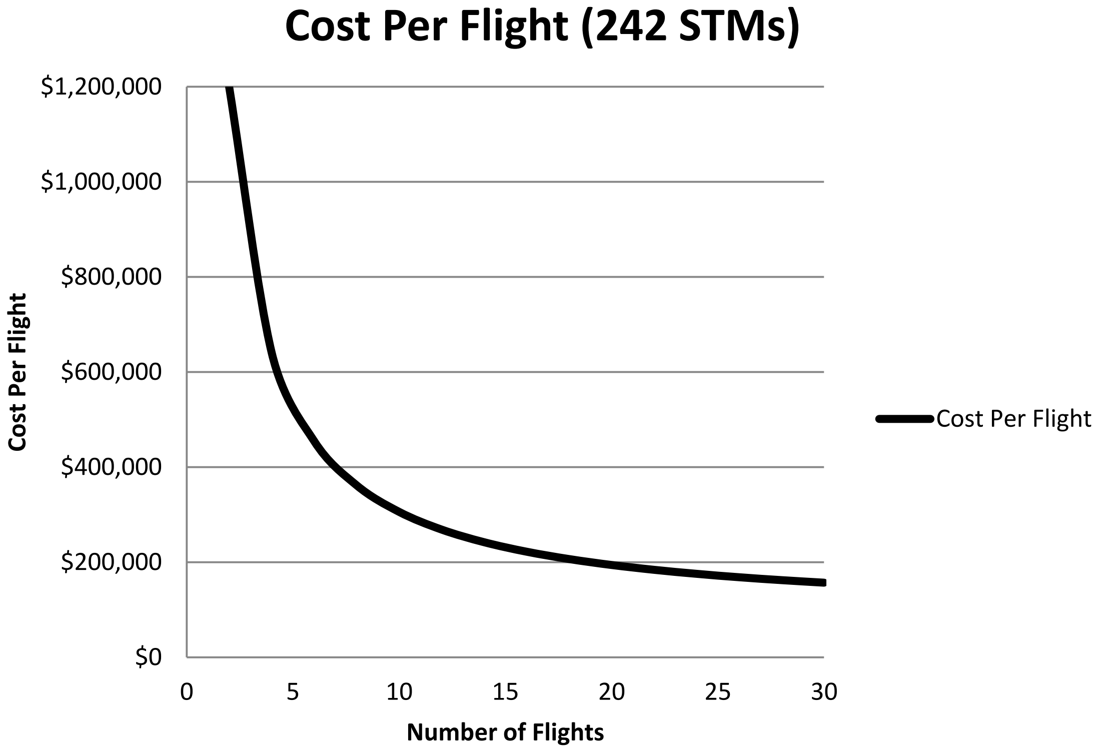

Figure 18. Cost Per Flight for total acquisition quantity of 242 STMs

As Figure 18 demonstrates, assuming a minimum acquisition of 242, for a total PAUC of $2,212,000, the cost per flight event rapidly drops, dropping below a per-flight cost of $300,000 at the 10th flight event before dropping further to $200,000 per flight at the 18th flight event. This represents approximately one-fifth the current total cost of an ESSM. Assuming a greater acquisition quantity results in an even more marked cost savings, as shown in the following figures.

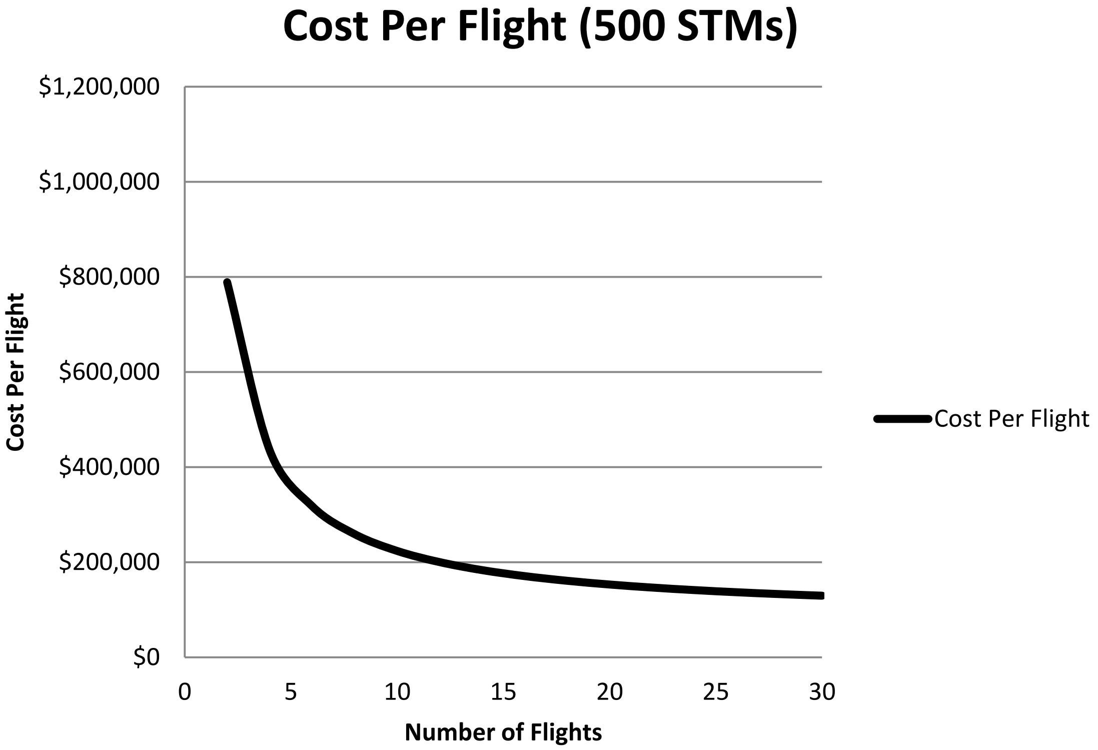

Figure 19. Cost Per Flight for total acquisition quantity of 500 STMs

If the total acquisition quantity is increased to 500, as depicted in Figure 19, the total cost per flight event drops below $200,000 after only 12 flights, and drops to roughly one-sixth the cost of an ESSM with WDC after 25 flights. Even if the cost per overhaul was increased to a value of $100,000, the cost per flight would still fall to $200,000 after 14 flights.

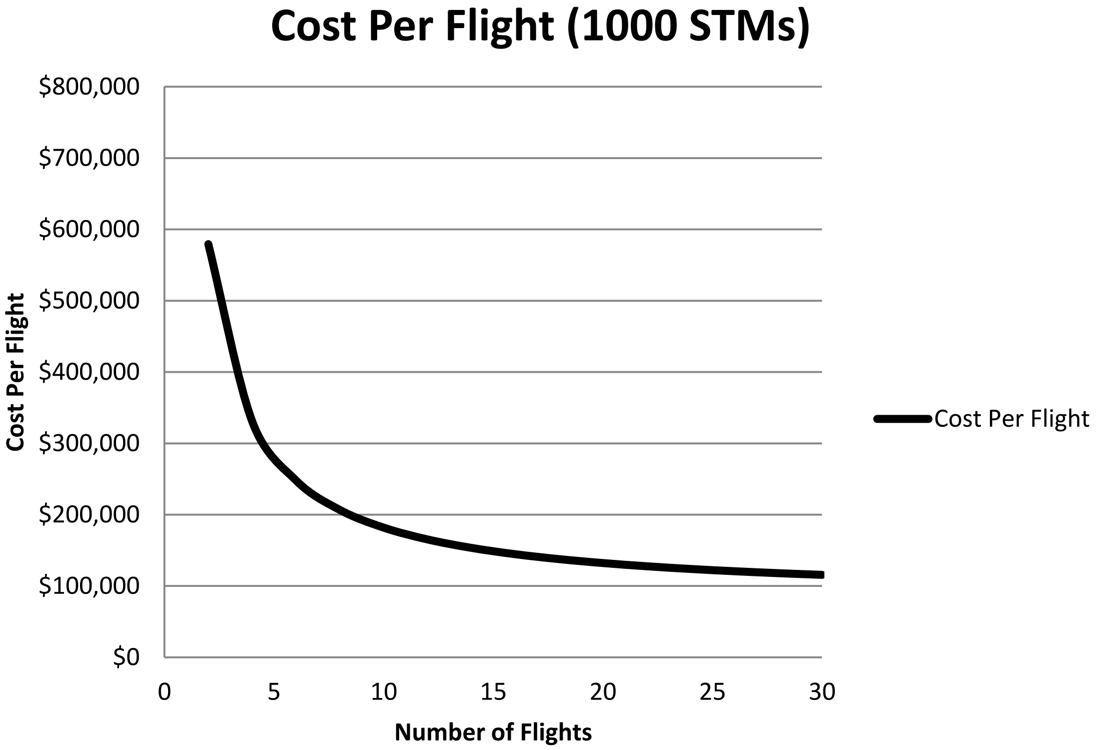

Figure 20. Cost Per Flight for total acquisition quantity of 1,000 STMs

Finally, if the assumed total acquisition quantity is set to 1,000 STMs, as depicted in Figure 20, the cost per firing is reduced to $200,000 after only 8 flights, and drops to $125,000 after 23 flights, less than one-eighth the cost of an ESSM with WDC.

C. STM APPLICATIONS

This chapter should make abundantly clear the importance of both leveraging the existing NATO Sea Sparrow coalition of nations as well as maximizing the applicability of the STM to reduce costs associated with RDT&E and acquisition. Although the majority of this report has focused on the Aegis-configured STM, other variants are possible and should be pursued in conjunction with the development of the Aegis round. Ideally, there would be as few physical differences as possible between rounds configured for use with Aegis and other combat systems. Potential missiles that the STM could emulate for the purpose of readiness verification or crew proficiency included the NATO Sea Sparrow and Evolved Sea Sparrow, both of which are adaptable to numerous launching and control systems, and both of which are widely used by both U.S. and foreign militaries. The Patriot Missile System would be another obvious system to leverage, reaping the benefits of Joint development and further sharing development costs. Future configurations could support both the Zumwalt and Ford-class X-band guidance radars, as well as emerging foreign systems such as PAAMS.

D. SUMMARY

The results of the foregoing analysis indicate that significant cost savings are possible with the STM when compared to other missile types. This result is dependent on the assumptions made throughout the chapter. Specifically, if developed in conjunction with foreign militaries and designed to be as widely configurable as possible, the STM is an affordable option for increasing both readiness and proficiency. The cost estimation suggests a cost of between one-third and one-eighth the cost of an ESSM per firing event, depending on the total number of STMs acquired, the overhaul cost incurred for each firing event, and the number of flights conducted with each airframe. It is important to note that the cost estimation performed here is superficial in nature due to the conceptual nature of the STM. The costs associated with developing and fielding the STM could change significantly based on decisions made in design and requirements.

VII. RECOMMENDATIONS AND CONCLUSION

The preceding discussion and analysis preliminarily indicate that the STM concept is feasible to the extent that can be determined in a report of this scope. Additionally, given the assumptions made during the cost estimation of the STM, it appears that the STM will be cost effective when compared to use of missiles such as the Evolved Sea Sparrow Missile for proficiency or readiness evaluation. This chapter examines the benefits derived from the use of the STM and proposes recommendations for further program development and study.

A. COST BENEFIT ANALYSIS

As detailed in Chapter VI, based on the underlying assumptions, the STM is estimated to have a programmatic cost per firing event of between $125,000 and $330,000. This number is ultimately dependent on the sharing of RDT&E costs, the total procurement quantity, and the number of flight events each round ultimately conducts. When compared to the acquisition cost of the ESSM, this range represents a cost savings of between 87.5% and 67%. Compared to the legacy SM-2 rounds in inventory, the cost savings is not as dramatic. However, it is important to note that the firing of the STM does not deplete available inventories of either ESSM or SM-2. This is critical, as the SM-2 is no longer being procured.

It is also important to note that firing of the STM can never replace live missile firing events, as it is important that performance data for the actual missiles is acquired so that the missile performance can be characterized. Firing events utilizing ESSM and SM variants will still need to be regularly conducted to evaluate the performance of the missile against threat-representative targets and generate an estimated probability of kill for the seeker/warhead configuration tested. There is no reason why firing events conducted solely for proficiency require the use of an actual missile. Rather, the precise number of actual missile firing events required to calculate the performance characteristics of that missile over time within a reasonable confidence interval should be determined. Firing events beyond this number can then be assigned as STM events.

The cost/benefit analysis of the STM is reinforced by an examination of firing event objectives. Enclosure four of COMPACFLTINST/COMUSFLTFORCOMINST 3590.12 lists 48 data collection points for ESSM firings, and 49 for a firing event utilizing an SM-2. Of these, all but two would be achieved with an STM firing. These are the fuse performance of the missile and the realized miss distance.[37] With an STM's limited terminal performance due to a design bias toward target avoidance, the realized miss distance would be greater than that of a missile employing terminal homing guidance. This should trigger an automated "No Kill" alert from the combat system, as the target continues inbound and the missile begins its post-intercept maneuvering. Additionally, with no warhead, no fuzing data can be gathered. This data would have to be collected during missile performance firings. Despite these limitations, a plethora of valuable data about the firing unit's combat system will be gathered. Key data points include: weapon system automated kill evaluation assessment; Fire Control System performance; overall missile performance; initial target detection range from firing unit; and target lock-on range from firing unit.

In addition to these data points, the STM will gather additional data above and beyond the required data collection. This would include the frequency and amplitude of received terminal guidance, both rear-reference and reflected from the target. Additionally, the amplitude, frequency, and time of receipt for missile uplink commands would be recorded. By making allowances for additional growth weight and space in the initial design, further data gathering would be possible utilizing future technologies.

Overall, the STM would allow collection of 95% of required data collection points at a fraction of the cost of an ESSM and without depleting the inventories of the ESSM or SM-2 unnecessarily. Additionally, a readiness and proficiency benefit would be realized through watchstander experience gained during the firing exercise, as well as through performance of pre- and post-fire maintenance checks. For these reasons, pursuing the further development of the STM has the potential to provide benefit to the fleet while reducing expenditure on live firing exercises.

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[37] Commander, U.S. Pacific Fleet, COMPACFLTINST/COMUSFLTFORCOMINST 3590.12, *Data Collection and Reporting of Surface Missile System Missile Firing Exercises*, May 16, 2013, Encl (4).

B. RECOMMENDATIONS

It is recommended that the STM concept be considered for further development and potential initiation as a program of record. Further study should be conducted on the feasibility of the functional solutions investigated in Chapter IV. Additional work needs to be done by experienced engineers on determining the number of flights possible from an airframe, and finding ways to extend the lifespan and increase the maintainability of the STM. The cost estimate detailed in Chapter VII would benefit from an independent review and further cost estimation efforts based on parametric or engineering means.

Further study should also focus on maximizing the compatibility of the STM concept. Using the ESSM as a model, it should be determined what hardware and software can be utilized to provide maximum compatibility across a range of in-service U.S. and foreign weapons systems. Design work should focus on determining what components would be applicable across the range of configurations, and which components, such as antennas, would need to be changed based on which combat system the STM is used with. This will allow a more detailed cost analysis that takes into account the required physical differences between configurations. Additionally, it will help to determine which configuration variants are worth pursuing, given the cost of modification balanced against the increase in the potential user base.

Lessons learned from the detailed design of the STM could be applied to other current or future missile programs as well. The ability to design a missile for recoverability would benefit future development of missile systems, as it would allow recovery of some or all of the missile components following a live-fire test event. This would not only reduce the cost of conducting repeated test events that do not aim to test the fuzing or warhead performance, it would also allow test engineers to more accurately determine causes of test failure. For example, instead of just noting an intercept failure due to excessive miss distance, engineers would be able to examine the seeker head and determine physical causes of component failure. Such prototypes could be retained and used to validate software or hardware updates throughout the program life cycle.

C. CONCLUSION

In closing, the STM represents a novel means of increasing readiness without incurring prohibitive cost. As the Navy seeks to chart a course through the coming years of budget contraction, fleet readiness must be preserved to maintain the viability of our surface combatants. The STM may only provide a modest contribution toward this goal, but every means available to preserve our fighting ability and continue to improve the training and thus readiness of our personnel should be examined and utilized.

GLOSSARY OF TERMS

Bleed-off	Aerodynamically reducing airspeed through drag or gravity
Command Destruct	Aegis function that orders self-destruct of missile in flight
Dogbox	Area designated as danger zone for missile firing exercise.
DTT	Synthetic target generated by AN/SPY-1 computer
Non-Organic Asset	Any asset that is not a part of the ship or group
Porpoising	Phenomenon where missile propels itself repeatedly into and out of the water.
Watchstander	Personnel standing watch in specific role
Watchstation	A specific role or position normally manned by watchstander

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LIST OF REFERENCES

AcqNotes. “JCIDS Process; Functional Solutions Analysis.” Accessed February 12, 2014. http://www.acqnotes.com/Acquisitions/Functional%20Solutions%20Analysis%20.html.

Aeroweb. “Evolved Sea Sparrow Missile.” Accessed April 27, 2014, https://www.bga-aeroweb.com/Defense/RIM-162-ESSM.html.

BAE Systems Land and Armaments. “VLS Mk 41 Canisters.” Accessed April 14, 2014. http://www.baesystems.com/download/BAES_046051/vls-mk-41-missile.

Balisle, Phillip. *Fleet Review Panel of Surface Force Readiness*. Annapolis, MD: Galrahn, February 26, 2010, 43, http://www.scribd.com/doc/43245136/Balisle-Report-on-FRP-of-Surface-Force-Readiness.

Blanchard, Benjamin, and Wolter Fabrycky. *Systems Engineering and Analysis* 5th edition. Upper Saddle River, NJ: Prentice Hall, 2011.

Chairman of the Joint Chiefs of Staff. CJCSINST 3170.01F. *Joint Capabilities Integration and Development System.* May 1, 2007.

Chairman of the Joint Chiefs of Staff Instruction CJCSINST 3170.01H. *Joint Capabilities Integration and Development System.* January 10, 2012.

Commander, U.S. Pacific Fleet. COMPACFLTINST/COMUSFLTFORCOMINST 3590.12: *Data Collection and Reporting of Surface Missile System Missile Firing Exercises*. May 16, 2013.

Department of Defense. *Selected Acquisition Report: Standard Missile-6.* Arlington, VA: Defense Acquisition Management Information Retrieval, May 21, 2013. http://www.dod.mil/pubs/foi/logistics_material_readiness/acq_bud_fin/SARs/2012-sars/13-F-0884_SARs_as_of_Dec_2012/Navy/SM-6_December_2012_SAR.pdf.

———. *2010 Quadrennial Defense Review Report*. Washington, DC: DOD, February 2010.

Lagrone, Sam. “The Next Act for AEGIS.” *USNI News*. Last modified May 7, 2014. http://news.usni.org/2014/05/07/next-act-aegis.

NASA. “Solid Rocket Boosters.” Last modified August 31, 2000. http://science.ksc.nasa.gov/shuttle/technology/sts-newsref/srb.html.

Office of the Chief of Naval Operations, *Report to Congress on the Annual Long-Range Plan for Construction of Naval Vessels for FY2014* (Washington, DC: Office of the Chief of Naval Operations, May 2013), 5

Raytheon Corporation. "Evolved Sea Sparrow Missile." Accessed April 21, 2014. http://www.raytheon.com/newsroom/rtnwcm/groups/public/documents/image/rms_rtn_essm_pic04.jpg.

Schneider, Leo. "VLS: A Challenge Met, An Old Rule Kept." Paper presented at the 24th Annual Technical Symposium, April 1987. Accession Number: ADA183944. Accessed from http://oai.dtic.mil/oai/oai?verb=getRecord&metadataPrefix=html&identifier=ADA183944.

United-States-Map.com. "Large Map." Accessed June 13, 2014. http://www.united-states-map.com/tabloid.htm.

U.S. Department of the Navy, *FY 2014 President's Budget; Justification Book Volume 1; Weapons Procurement, Navy*. Washington, DC: DON, April 2013.

———, *FY 2013 President's Budget; Justification Book Volume 1; Weapons Procurement, Navy*. Washington, DC: DON, February 2012.

———, *FY 2006 Budget Estimates; Justification of Estimates; Research, Development, Test, and Evaluation (BA-5), Navy*. Washington, DC: DON, February 2005.

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