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Naval Topside Design: Learning from the Past, Shaping the Future

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ABSTRACT

Just as 21st century Naval warfare is going through a transformation in roles and missions, early results of this change is being seen in the topsides of Naval combatants. The pace of the transformation is driven by modifications and upgrades in the threat, by new technology and by changes in business practices. The traditional view of our father's Navy, a Navy constructed of "steel ships and iron men", founded in the post WWII era, is gone. A good historical indicator to the change in surface warfare is evident in views of surface ship topsides. Increasing demands for additional capability and new technologies are being worked into existing ships of the line. At the same time, some very new forms and materials along with new system architectures are showing up in the blue prints (computer screens) of our future fleet ships. While we design, build and deliver Naval combatants optimized around an aircraft carrier battle group or amphibious ready group foundation, radically different ship concepts, to be utilized in unconventional force deployments are being actively studied. This paper will discuss the state of topside design in the U.S. Navy, the technologies and processes that are keeping our active fleet current, the evolving threat, and our response to it as realized through the topside designs of our next generation Naval combatants. The challenges (technical, organizational, business) we face in crafting the ship topsides of the Navy after next will be discussed.

1.0 INTRODUCTION

Naval topside design for combat ships is by necessity a search to find innovative ways to meet competing requirements for system functionality within limited space, weight, and cost constraints. The combatant topside must accommodate a wide array of Combat Systems (CS), Command, Control, Communication and Intelligence (C3I) and Hull, Mechanical and Electrical (HM&E) functions while maintaining maximum functionality of all systems to do their individual jobs. And at the same time the topside must continue serving the basic ship operational functions such as underway replenishment (UNREP), refueling at sea (RAS), flight operations, small boat deployment, docking and maneuvering, navigation, and personnel movement. All while meeting overall ship signature requirements and imposing minimal manning and operating impacts.

The challenge of the integrated topside design of a modern Naval surface combatant is a sophisticated assortment of weapons, electromagnetic (EM) radiators, and HM&E hardware as well as the form, material and structures that make up the foundation of the topside surface. Large numbers of antennas, transmitters, and receivers are required to meet radar, Electronic Warfare (EW), Information Warfare (IW), and communication requirements [Law 1987 and 1983]. An increasing inventory of EM systems is constantly being added to meet requirements for additional communications capability with greater imagery and data transfer capacity.

Ever since Guglielmo Marconi's successful experimentation with the radio phenomena at the turn of the 20th century, there has been a steady increase in the applications of electromagnetic based capability to the military. In the past two decades, this increase has shown an exponential trend on Navy ships. As a result of the increasing use of the radio frequency (RF) spectrum, there has been an almost uncontrolled proliferation of antennas on ships. For example, current Guided Missile Destroyers (DDG) have approximately 80 antennas. Each of the "bubbles" in the DDG 51 pictorial (Figure 1-1) indicates an antenna system. Aircraft Carriers (CVN) have nearly 150 antenna systems aboard.

The consequences of this growth have been unacceptable increases in:

- antenna siting issues
- signal masking and obstruction
- weight, volume and moment issues
- maintenance and repair costs
- electromagnetic interference
- radar cross section

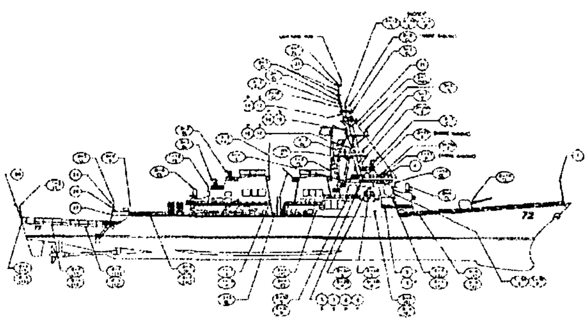

Figure 1-1. Pictorial of DDG 51 Topside

The consideration of a ships electromagnetic signature is an additional complication adding to the already difficult topside integration task. The required target strength of the ship (and thus the topside) is steadily decreasing in magnitude while at the same time increasing across the frequency spectrum. The need for reduced RF, Infra-Red (IR) and Electromagnetic (EM) signatures presents its own challenges for the topside designer. Traditional ship designs have very large radar cross-sections. As a result, modern designs must incorporate "clean" topside concepts. This can be difficult to achieve while maintaining all the functionality of topside equipment. In addition, Infra-Red (IR) signature control presents its own unique challenges, not only for control of exterior hot spots, but also for control of the large area surface radiance (the glow an operational ship presents against a cold sea or night sky background). Finally, as the RF emissions increase with the antenna numbers on ships, the need to control the active emissions to mitigate hostile exploitation has become increasingly more important to RF system engineers. For a qualitative assessment of this trend, one only needs to look at the topside geometry of past, present and future destroyers (Figure 1-2); the evolution towards more 'stealthy' topside design is apparent.

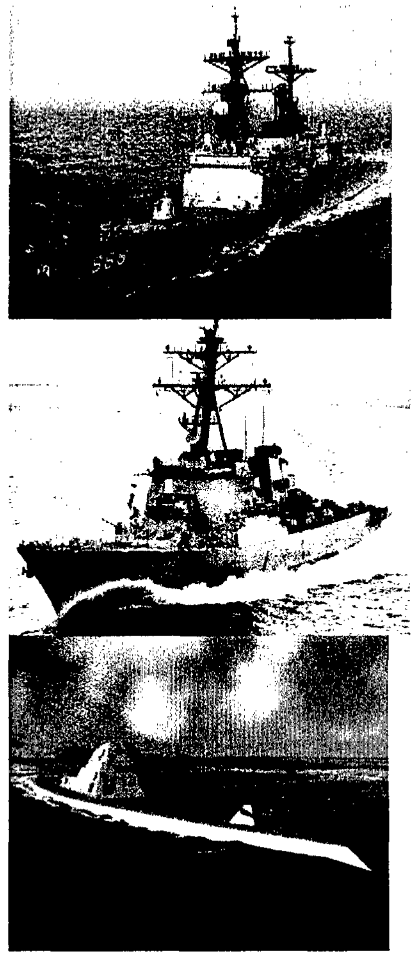

Figure 1-2. DD 963 Class, DDG 51 Class and DD 21 Class

The traditional topside design approach is based on developing separate systems and associated antennas for each individual topside function. The individual topside systems are then arranged seeking an optimal solution that meets the requirements of all topside design issues. The recent volume of Navy messages addressing system blockage and EMI problems, and the expenditure of efforts to mitigate these problems has shown this strategy to be unacceptable. Improved topside design process and procedures are a critical need. The combat effectiveness of Navy ships is limited by the ability to provide acceptable topside designs. The creation of affordable designs with acceptable antenna performance and reduced signature is the challenge of a new Integrated Topside Design (ITD) strategy. This strategy requires innovative engineering approaches due to physical constraints such as weight and moment design limits. Hence, it is necessary to achieve substantial space and weight savings by the use of advanced composite materials for superstructures and deckhouses. Additionally, the use of such composites can enable new possibilities for the deployment of advanced antenna systems while offering advantages for signature control.

This expansion of requirements and change in the 'look' of combatant topsides is in response to the evolutionary improvements in radar tracking and missile terminal guidance technology coupled with the widespread proliferation of these technologies. Although it should be clear from the preceding discussion that effective topside design does not hinge on a single technology area, the recent emergence of these increasingly difficult signature requirements will dramatically influence the roll of the topside designer relative to future ship design programs. A successful topside design for future ships will require innovative topside design and signature control strategies that are developed, designed, installed and operated with a total integration of all other ship systems. Thus, the topside design process for future ships must be a full integration of often conflicting and diverse technologies that take advantage of the discipline instilled through the Total Ship Systems Engineering (TSSE) trades.

The goal of this paper is to discuss the health of topside design practices in the current Navy including the technologies and processes that are keeping our active fleet current. The evolving threat and our response to it as realized through the topside designs of our next generation Navy combatants. Finally, we'll explore the challenges we face in crafting the ship topsides of the Navy after next.

Analytical Dimensions of Topside Design

Every system is part of some larger system, and must interact with other elements of the larger system to accomplish its purpose. An effective partition to focus an analysis of this embedded system construct is on the interface of the particular system of interest with the other systems and higher level system-of-system formulations. The topside, as a system-of-systems enabling shipboard operational performance characteristics to be realized, is just such an analytical domain where the interfaces become the primary focus of the topside design. Figure 1-3 shows a figurative boundary between the topside elements and the ship environment. This can be useful to understand the dimensions of the interfaces that must be accounted for during any topside design evolution.

There are many aspects and characteristics of the topside design that must be assessed as part of any design evolution (new ship design or fleet modernization). Following are some examples of the types of analytics that must be conducted to assess the operational performance of the topside itself and/or of systems and materials that may reside within the topside. This is not an exhaustive list, but only a few examples of the types of analysis that must be conducted either holistically as part of new ship design, or as piece wise analytics for the introduction of a new system into an existing ship topside. Later in this paper, a modeling and simulation design executive tool will be discussed that helps to integrate the assessment process and link tool sets to a common ship description.

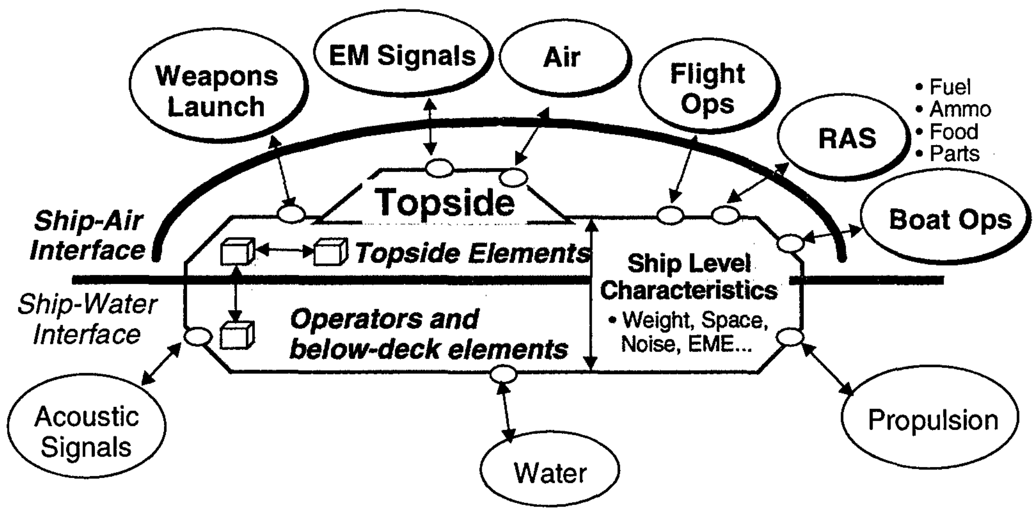

Figure 1-3. Ship Topside Boundary Conditions

Weapons Integration – Toxic fumes from rocket motor ignition, temperature calculations for the application of ablative materials and blast shields to handle the tremendous heat from missile launches (as illustrated in Figure 1-4), and large caliber gun blast and overpressure calculations to protect other nearby sensitive topside elements are just a few of the weapon system integration assessments that must be conducted to successfully integrate a hard kill weapon or decoy launcher into the ship topside environment. Figure 1-5 shows an example of the temperature profile surrounding a VLS launch.

Figure 1-4. VLS Launch

Coverage/Cutout – Systems located topside usually have a need for maximum coverage of the external spherical volume surrounding the ship. The expected coverage or view that a system will have to the exterior environment and the control of where a system can point (and just as important, where it can't point) is assessed through blockage analysis tools to develop coverage diagrams and weapons cutouts. Figure 1-6 depicts an example of a cutout (in mercator projection) of a missile systems fire and no-fire zones

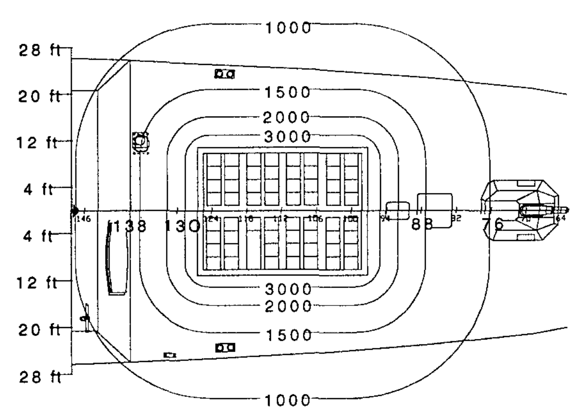

Figure 1-5. Missile Blast Stagnation Temperature Contours (F)

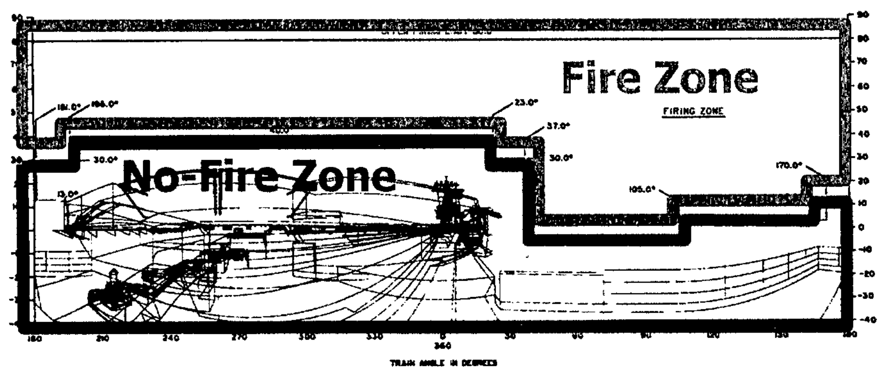

Figure 1-6. CAM Cutout Analysis for Weapon System Coverage

EM Signals – Electromagnetic based systems (communication and surveillance antennas/arrays) require a significant detailed analysis due to the interaction of electromagnetic waves with surrounding shipboard structures. Surrounding structures and other nearby systems will cause negative effects on the performance of an antenna element. Beam pattern and side lobe degradation as well as system sensitivity and electromagnetic interference all need to be assessed as part of the topside design analysis. Figure 1-7 depicts an example of an electromagnetic analysis of beam degradation due to surrounding mast structures.

Weapon System Performance – To assess overall weapon system performance, a series of

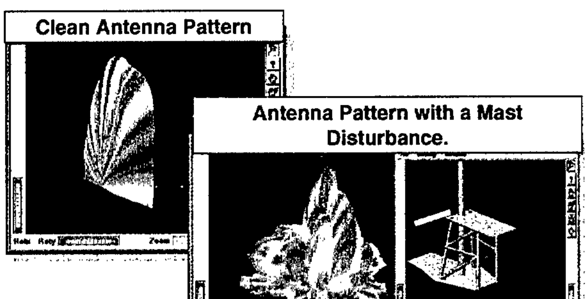

Figure 1-7. Antenna Beam Distortion Due to Surrounding Mast Structure

previously discussed analysis (weapon coverage, cutout, antenna beam performance) are combined and assessed against a potential threat in an operationally realistic scenario. Figure 1-8 shows the results of the combination of hard kill weapons (missiles) and soft kill weapons (electronic warfare systems) as evaluated for simultaneous operations against a stressing threat to the ship. The results of this analysis can then be measured against capstone requirements for combat capability at sea. Deficiencies can then be identified and a sensitivity analysis conducted to identify which combat system elements are driving the result. A subsequent design iteration can then address the deficiency most effectively [Bobrowich and Douglas 1992].

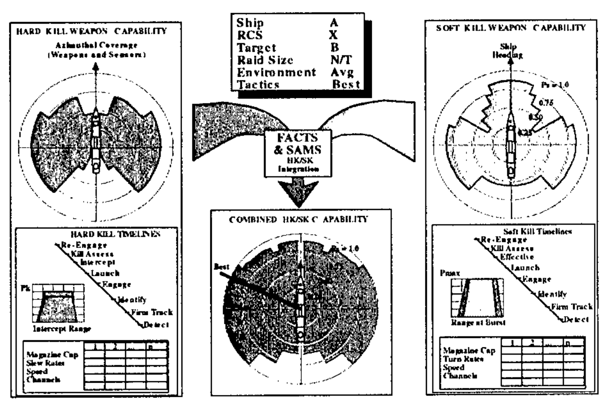

Figure 1-8. Warfare Analysis, Self Defense

Air Wake/Flow – Specifically, with the introduction of gas-turbine propulsion, the air flow analysis into and out of a ship through the topside has taken on increasing significance due to volume, temperature, particulate of exhaust into the topside and back pressure characteristics to the propulsion plant. Also the introduction of stealthy topside forms has created a condition wherein smooth surfaces of the topside have created what equates to a new design condition, one of laminar air flow across the topside surface. The laminar flow creates much more significant sheer forces to arriving and departing aircraft (specifically rotary wing aircraft and aft flight deck designs). Figure 1-9 depicts an air-wake analysis recently conducted as part of the LPD 17 design with the composite mast structures topside.

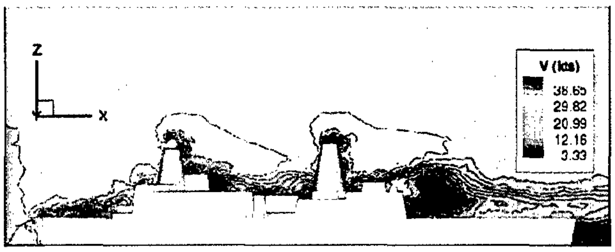

Figure 1-9. Air Wake Analysis of USS San Antonio (LPD 17)

Flight Deck Safety – The envelope around which an aircraft can be operated safely is tightly controlled. Any topside design evolution around the flight deck areas of an air capable ship requires an assessment for flight safety and may require the re-certification of the flight deck for operations.

Replenishment at Sea (RAS) – The movement of fuel, stores, ammunition, and people must all be accounted in the topside design. Not only are the keep clear zones identified for the RAS/FAS stations that run up and down the port and starboard sides of the ships, but also the movement of the stores over the topside (usually by man or by small pallet vehicles) to the applicable strike down location into the ship must all be accommodated.

Boat Operations – Boats of various kinds must be deployed and recovered from off or through the topside. Traditional techniques such as use of the ships crane and/or boat davits are being replaced in newer ships with hidden signature control curtains and behind signature controlled structures. As the deployment concepts for boats become uniquely assessed for each ship class, the utility of deployment and recovery simulations are becoming very important to the topside designer. Figure 1-10 depicts a simulation of boat deployment/recovery operations on the USS San Antonio (LPD 17) Class.

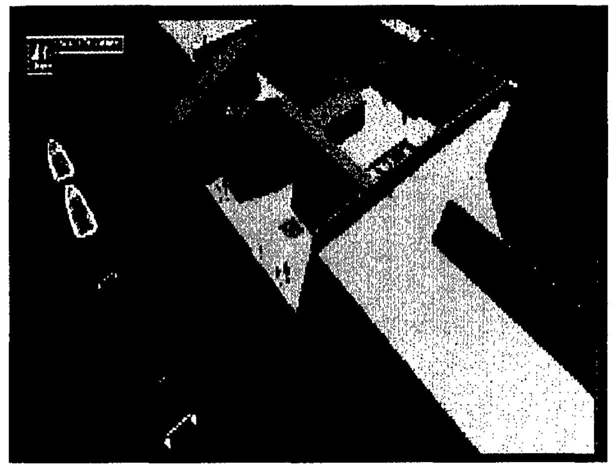

Figure 1-10. Boat Handling Simulation on LPD17

Structural Analysis – Ship topside structures (deckhouse, mast, platforms) require continuous structural re-assessment for the introduction and/or removal of systems/equipment topside. Not only are the traditional structural engineering assessments necessary for the introduction of topside systems but also modal analysis is required to understand the stresses imparted in topside structures from shock loads. Topside mast structures have been found to accentuate low frequency shock loads as they progress from the hull of the ship through the superstructure and into the mast. This effect has been so severe as to cause the complete failure of topside equipment foundations. Figure 1-11

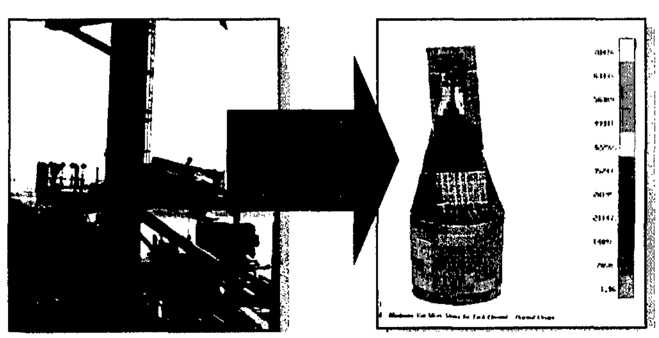

Figure 1-11. Mast Modal Analysis

shows a structural analysis of a mast/platform transition under shock stresses.

Signature Analysis – Topside signature analysis for those ships that have a signature requirement that must be met or maintained must be included in all aspects of topside design. The nature of the signature reduction problem is that any one item can dominate and control the signature of the entire ship. In addition the signature of any individual piece of equipment or of a complete system will often be controlled by how it is integrated into the ship topside structure. Signature budgets must be established for all topside elements and these budgets must be continually reviewed and updated as system development and topside design proceeds. The concern for signature control must be included at the beginning of system developments since it is often impossible and always expensive to "add on" signature control after fundamental system architectural design characteristics are detailed.

2.0 CURRENT NAVY

The Current Navy comprises those ships currently deployed or in various stages of industrial availabilities readying for deployment. As the tip of the spear of our operational forces "From the Sea . . .", the design attributes and performance characteristics of the systems, equipment, materials and architectures contained in the topsides of these ships must work, as predicted, with clearly characterized capabilities and limitations. The topsides of our Current Navy surface ships have a very wide range of challenges. These challenges range from the traditional topside corrosion problems that have plagued metallic ships at sea ever since the USS Monitor to network centric warfare capabilities of the Naval Battle Force now enabled through electromagnetic emissions on and off the ship.

With rare exception (SPY-1 Radar installations on AEGIS ships), the topsides of our Current Navy are a consolidation of many independent system developments that are mounted to or hung off of traditional box deckhouse and skeletal mast structures. Construction tends to be traditional maritime steel and aluminum fabrication with a strong focus in design on pre-fabrication and production efficiency.

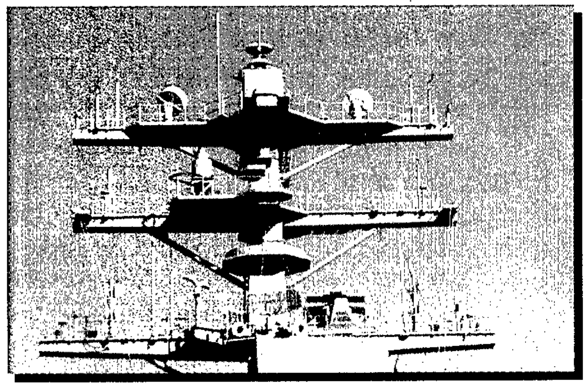

Figure 2-1. USS Nimitz (CVN 68) Mast forward view looking aft

Figure 2-1 shows the new mast structure of the recently completed Refueling Complex Over-Haul (RCOH) for USS Nimitz (CVN 68). This mast is typical in form and design of our Current Navy showing the plethora of antenna, sensor and navigational aid systems dispersed on horizontal yardarm structures. The heaviest elements are arranged on or near the main mast vertical support element. This location, out of structural necessity with a skeletal design, challenges these larger systems to look around or through the large metallic structure, a feat particularly challenging for RF and optical systems, and leads many times to reduced performance and/or complete blind zones of coverage.

The USS Nimitz mast example is a bit unique in Current Navy topside integration in that an entire new mast was designed, fabricated and installed as part of this major industrial event. The design originated from the mod-repeat design evolution of the USS Ronald Reagan (CVN 76), the next new construction aircraft carrier recently christened on March 5, 2001. Due to very similar combat system and C3I architectures of these two ships and an artifact of their industrial schedules, the USS Nimitz version of this mast design has gone to sea first.

A more traditional Current Navy example of topside design is shown in Figure 2-2 where a series of independent Ship Alteration Records (SARs) are being integrated into an existing superstructure with many pre-existent and unrelated systems surrounding them.

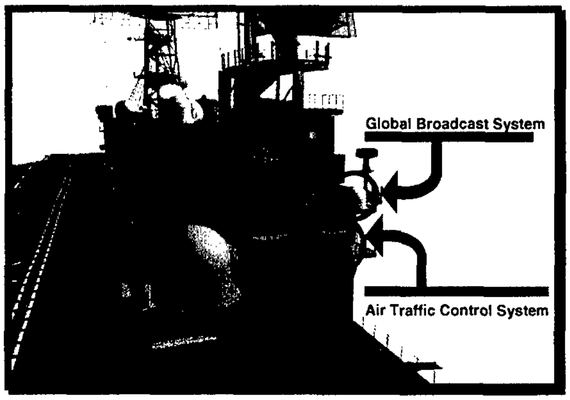

Figure 2-2. USS SAIPAN (LHA-2) Island aft view looking forward

In this typical case of system integration into a pre-existent topside, there is as strong a desire by the topside designer to understand and maintain operational performance of the current systems, as there is a desire to optimize the performance of the new proposed system. This could translate into various engineering assessments such as structural, air wake/flow, electromagnetic, weapons coverage and effects, sighting/blockage, safety, etc. In addition, overall ship assessments may need to be performed such as survivability, vulnerability, accessibility, maintainability, reliability etc. Unfortunately, although the desire is there to address all ship impacts of the new install on the current condition of the topside, the resources (funding and time) are usually not available.

The resources provided for integration are tied to the installation dollars of the particular program, which limits the scale, and scope of engineering activities that can be performed. Further, the time in which to perform the many trade-off and analysis activities required to locate the new topside elements is increasingly becoming compressed as the operational tempo of our Current Navy continues to increase while the industrial availabilities are becoming shorter and shorter.

There is a strong desire by the technical community to gain more efficiency in the engineering evolutions (analyze once, use many times) by consolidating work packages and performing the integration design on a class or baseline basis. The development and maintenance of a Projected Class Baseline (PCB) design package is just such a product. Only through the consolidation of as many known ship alterations over the course of a 3-year period can the topside designer hope to keep up with the rapid pace of change. As a planning tool, the PCB becomes an enabler for the topside engineer to meet the challenges of the compressed schedules proposed under new milestones for the Fleet Modernization Program (FMP) (see NAVSEA ltr 09JUL01). This set of milestones is shown in juxtaposition with the battle force deployment schedule known as Deployment date less 30 months (D-30) in Figure 2-3.

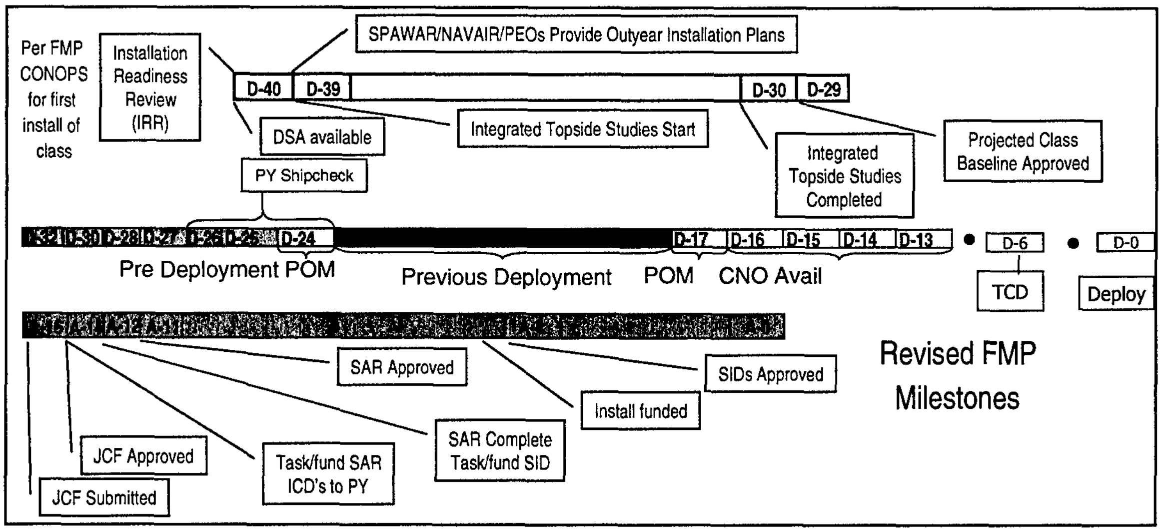

Figure 2-3. Timeline for Integrated Topside Studies

The time metric for D-30 relates to the 30-month period of planning and alteration execution prior to the scheduled next deployment of the ship with its Battle Group assets. While a span of 2 1/2 years (30 months) to plan for and execute an installation may seem like a considerable amount of time, one must consider the constraints on the topside designer to understand the need for this period. In actual execution, the time span covers a previous deployment cycle at D-23, so that the ship or ships are essentially unavailable for 6 months out of the D-30 cycle. This is relevant if early ship visits and/or surveys are required by design and planning teams early in the design process. This is important to note as the Ship Installation Drawings (SIDs) must be completed, approved and the work contracted out in time for the next ship alteration availability that starts at D-16 (or A0 on the FMP milestones). The location of the new system must be completely worked out prior to the start of the SID or no later than the final ship check at D-25 or D-24. The topside design therefore must be completed 2 years prior to deployment or at 8 months prior to the next ship availability. Given the state of the art of integrated topside design analyses methods the topside designer would need to start at D- 39 to complete a first-of-class installation plan. The 9-month study would result in an approved PCB, which could then be used to support emergent system installation studies or unique situations due to hull-to-hull variations within a class. The initial investment up front in the PCB enables a rapid response for the follow on ships in the class within the constraints of the FMP milestones.

The engineering design tasks of locating one system or many systems onto the topside of a ship are essentially the same. The importance of including as many systems in the design phase as possible, however, permits weighing the impacts of the installation in an attempt to optimize the arrangement. Unfortunately on today's extremely crowded topsides this often results in a choice amongst several bad options. Even the best system engineering practices applied to integrated topside design will not be able to solve the many competing needs for uncluttered space or surrounding volume. The designer can only hope to minimize impacts to the high priority systems and provide as much functionality for the new systems as possible. How do we propose to accomplish this? The Integrated Definition methodology IDEF Level 0 process chart for Current Navy topside design is shown in Figure 2-4. This chart diagrams the various technical steps necessary to lead to an Integrated Topside Design. Although not a flow diagram, the procedure can be seen as an iterative process requiring review by the many Subject Matter Experts (SMEs) for each discipline noted.

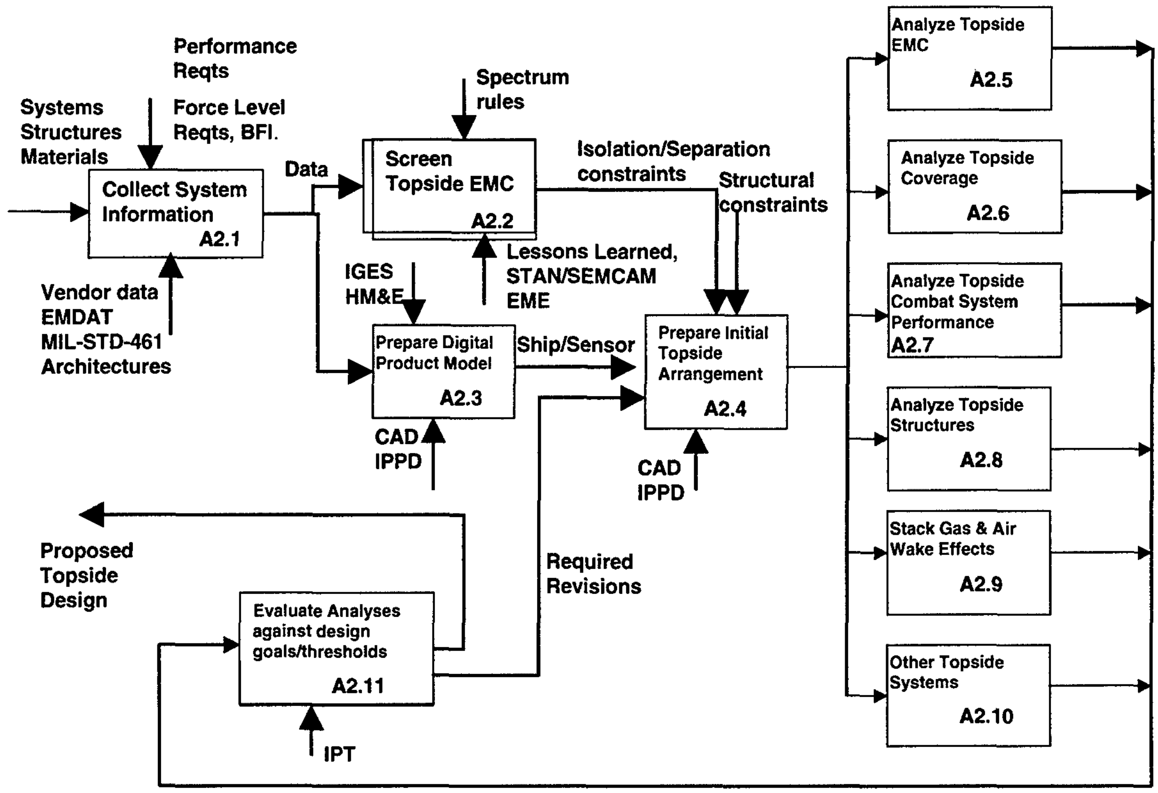

Figure 2-4. Integrated Topside Design Process Diagram

The steps for performing the integrated topside design can be summarized as:

1) Receive your requirements,
2) Gather needed data on the systems and current ship configuration,
3) Update 3D computer models of the systems and the ship,
4) Prepare an arrangement,
5) Analyze the impacts to ship system performance due to the added systems and placement,
6) Revise the arrangement as needed until an optimal arrangement is achieved.

This process requires experienced engineers from combat systems, C4I systems, aviation systems, and Naval architects. A thorough analysis must provide sufficient information to support a design decision. This decision is based upon an evaluation of the impacts across the elements of an integrated design check list (draft SPAWARINST 3090.1) provided in the below Table 2-1.

Table 2-1. Integrated Topside Design Check List

Constraints/Inter-faces	Ensure appropriate constraints are applied. Examples are cable or waveguide maximum lengths, minimum height above water line, maximum allowed height above water due to bridge restrictions, etc.
Blockage/Coverage	The proposed location is blocked at least partially or at least part-time, or both, from 100 % transmit/receive operation at 100 % reliability. Coverage of surrounding systems is not significantly impacted.
EMI/EMC	Electro-Magnetic Interference/Electro-Magnetic Compatibility.
RADHAZ	RADiation HAZard.
HERO/HERP	Hazards of Electromagnetic Radiation to Ordnance/Hazard of Electromagnetic Radiation to Personnel
RCS	Radar Cross Section
Impact to combat weapons systems	Ensure that the selected location does not degrade sensor or missile illuminator performance. Assess any impacts to the ESM/ECM and direction finding systems.
Impact to Existing Systems	Ensure that selected location does not block other emitters, navigation aids, foul boat davits, interfere with chocks or cleats or any way adversely impact ship's operations.
Maintenance Accessibility	Ensure that selected location provides appropriate access to conduct routine maintenance.
Missile/Gun Blast Effects	Note proximity of selected location to missile launch systems and gun mounts, with respect to vibration, smoke and heat from weapons systems when fired. Evaluate impact to coverage and firing zones.
Flight ops/jet blast/helo down wash/ acrft parking	Ensure all aviation support systems are unimpeded, consideration for hazards of jet blast, required clearances are applied to location decisions.
Green Water Loading	Take into consideration the proximity of the selected location to salt water spray, wind, etc. while the ship is underway.
Stack Gas Effects	Ensure that selected location is as free as possible from the effects of engineering plant exhaust.
Weight/Moment Impact	Take into consideration the weight of the antenna and distance form ship's waterline in determining the weight/moment characteristics.
Survivability	Overall consideration of all effects on antenna placed in the selected location. Note: while optimum coverage may be gained, it may be off-set by adverse effects from weather, etc. Ensure the system shock and vibration capabilities are compatible with selected location.

Various methodologies can be used to support the decision making process. In each case the importance of the above elements of the checklist are decided, ranked and weighted. A numeric score must be arrived at which summarizes the supporting analyses. Additionally, an effort has been made to bring in Fleet experts to assist in assigning operational weights to the topside systems under analysis.

The combined score for the topside arrangement therefore reflects the criticality of the system to the ship mission and any impacts to its performance due to the proposed arrangement.

An example of a recent study done for the LHD 7 illustrates the methodology for achieving a design decision. The antenna systems for the large deck amphibious assault ships listed in Table 2-2 were prioritized during a Amphibious Warfare Ship Sustainability and Modernization conference (msg DTG 141504ZSEP99) and promulgated by the ship program sponsor (msg DTG 020015ZOCT99). The relative weights or importance of each antenna were arrived at through discussions with combat system engineers and the ship design manager. The combination of antenna relative ranking with the assigned weight was coined the antenna system importance factor.

Table 2-2. Antenna System Importance Factor

System	Weight
1. SHF (AN/WSC-6(V)5)	20.0
2. UHF SATCOM (Quad DAMA)	15.0
3. Challenge Athena (AN/WSC-8(V)2)	12.0
4. EHF SATCOM (Dual Systems)	11.0
5. GBS	8.5
6. AS-3439/U (Doughboys)	7.5
7. DWTS	6.5
8. EPLRS	6.5
9. SINCGARS	5.5
10. CHBDL	5.5
11. TV-DTS	0.5
12. INMARSAT B	0.5
13. AS-3439/U (Second set)	0.5
14. AN/SMQ-11	0.5

A subset of the topside design elements listed in Table 2-1 was chosen to be used as key performance parameters (KPP) for the study due to time and budget limitations. The KPPs were assigned weights as listed in Table 2-3 with the combination called a design factor.

Table 2-3. Design Factor Weighting Definition

KPP	Weight
Antenna Coverage (Total desired coverage)	50
No EMI (To or from other systems)	25
No Blockage (To other systems)	15
Antenna Survivability (Includes maintainability)	10
An optimum location has a Design Factor of 100	

The numeric value assigned to the KPP Antenna Coverage was determined from a topside design tool known as the Blockage Analysis Model (BAM). The total coverage available to the antenna for any given location was based on a complete view over 360° of azimuth and –10° to +90° in elevation expressed in a percentage of the requirement.

The value assigned for the KPP EMI was more subjective. Various electromagnetic coupling tools are available for use in a study [Rockway,et al 2001; also Baron and Cebulski 1992], yet each requires quite a bit of engineering interpretation as to the nature and impact of the predicted interference. EMI was evaluated as severe, medium, mild or none and given a point value of 75%, 35%, 5%, or 0% reduction respectively.

The KPP blockage was also assessed using BAM. The value assigned was based on the sum of the blockages to the other affected antennas. The percent blockage reduces the score.

The concept of the KPP survivability was interpreted much more simplistically than would be done in a complete warfare effectiveness assessment, again due to budget limitations. The reasoning was that all systems located topside were subject to some level of damage, therefore all systems would be somewhat similar. The difference between locations was evaluated only as to whether or not the antenna was easily accessible for maintenance. The value assigned was either 0 or 10 (or a factor of 0% or 100%), i.e., easy maintenance access isn't or is available.

For example an antenna location that resulted in:

95% of the desired coverage
95% of 50 = 47.50

Medium EMI to another system
(100-35)% of 25 = 16.25

A 5% blockage to another system
95% of 15 = 14.25

No survivability or maintenance access concerns
100% of 10 = 10.00

The total design factor in this example is 88.0.

Using the design factor value calculated in the above example (assuming applicability to system No. 4, EHF), the assigned overall value or score for that configuration would be (88 X 11 = 968) out a maximum possible score of 1100. Working through each antenna system proposed for the new topside using the method outlined above would result in a combined score for each grouping of antennas. A significant difference in total score supports a decision for the best overall arrangement. The chosen arrangement would then be passed onto the other SMEs for their own review and assessment.

Proceeding through the design process in a sequential fashion would be prohibitively time consuming. Thus, some means is needed to enable a parallel design process. The key to our needs lies in the rapid sharing of complex design information to all team members, much in the manner demonstrated by Simulation Based Acquisition a number of years ago. The same principles developed to speed and improve the design of new ships can be applied to the ships of our Current Navy as long as preliminary digital descriptions of the ship can be established. Pioneering work in this area has been performed in support of re-engineering the topside design process for in-service amphibious warfare ships. A demonstration of capability was accomplished during FY01 utilizing the framework of an Integrated Data Environment (IDE) known as LEAPS (Leading Edge Architecture for Prototyping Systems). LEAPS has been under development by NSWCCD for the last 5 years [Ames and Van Eseltine 2001] with the goal of promoting the easy and timely access of ship information by an integrated design team. The LEAPS data storage schemas permit a wide variety of parametric data, ship structural information (in the form of standardized geometries), parts libraries, relationships between the entities or parts, and a common access method. A pictorial diagram of the LEAPS environment is depicted in Fig. 2-5.

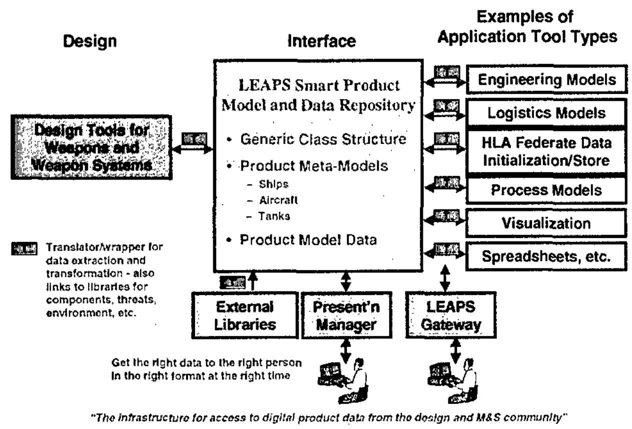

Figure 2-5. LEAPS Integrated Data Environment

Design and assessment tools used by Naval architects have been modified for use with the LEAPS environment. The modifications are basically translators to provide a two way interface to the required data stored within LEAPS. Currently, these tools can support ship concept design, signature reduction analyses and contract design. Recently a subset of the NAVSEA Electromagnetic Engineering (EMENG) analysis tools was modified to exchange information with LEAPS. The resulting capability, for the first time, enabled a reviewer to access the tool output remotely through the use of a common browser, instead of having to use the stand-alone EMENG analytical tool package them self. An example of accessing an antenna optical blockage analysis using the browser is shown in Figure 2-6.

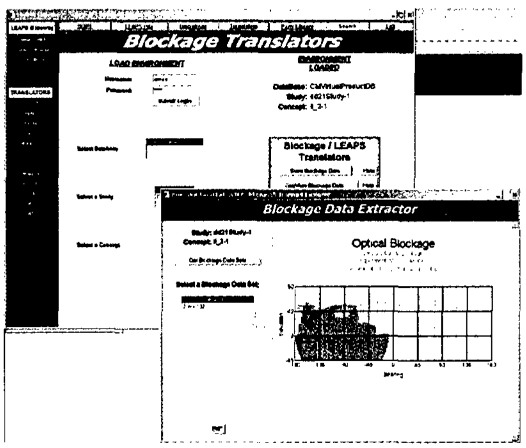

Figure 2-6. Browser View of Antenna Optical Blockage Analysis

The continued development of the ability to store ship model and analyses data in LEAPS will lead to the smart product model for ships of the Current Navy and enable affordable topside design analysis to be executed within the FMP timelines discussed earlier. The first step must be establishment of a smart product model for every major ship type/baseline/class and thus greatly enhance the ability to create topside arrangements that can be shared, adjudicated and approved within the tight timelines of the D-30 process.

3.0 NEXT NAVY

The Next Navy comprises those ships currently in the design/build stage (DDG final production, DD(X), LHA(R), JCC(X), CVN(X)) as well as ships which may undergo major forward fit and back fit upgrades to their capabilities (CGs, LPDs, and early DDGs). Due to the schedule of these ship introductions, the technology which can be considered is limited to items which can be fielded in the near- to mid-term. Fortunately, there have been a number of Science and Technology (S&T) investments and associated technology demonstrations that point the way to achievement of significant advances in the topside design that can be applied to these platforms.

The Advanced Enclosed Mast/Sensor System (AEM/S) Advanced Technology Demonstration (ATD) that was demonstrated on the USS Radford (Figure 3-1) is an excellent example of innovation in Integrated Topside Design that can provide near- and mid-term solutions. The AEM/S demonstrated the concept of large composite structures that can provide significant operational benefits to the performance of legacy antenna systems (reduced/eliminated gain reduction and antenna blockages from metallic skeletal masts) while improving the Radar Cross Section (RCS) signature and reducing the maintenance requirements of those systems contained within. The AEM/S concept also enables incorporation of new aperture concepts such as embedded HF antennas. The salient characteristics of the AEM/S include:

- **LARGE COMPOSITE STRUCTURE**
  87 3/4' High; 31' Dia; ~40 LTons
- **SHAPED TO REDUCE RCS**
  Hexagonal
  10° Slope
- **UPPER HALF**
  Frequency Selective Structure
  Integrated Communications
- **LOWER HALF**
  Reflective; RAS Option
  Metallic Shielding
- **BALLISTIC WAVEGUIDE TRUNK**
- **INTEGRATED EMI/EMP**

The AEM/S has already been selected for incorporation into the new construction USS San Antonio (LPD 17) baseline (Figure 3-2).

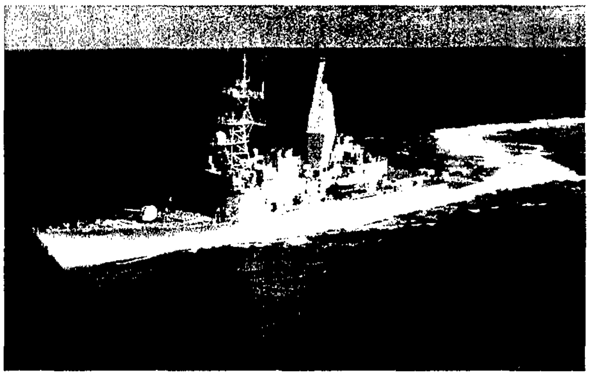

Figure 3-1. USS Radford with AEM/S Mast

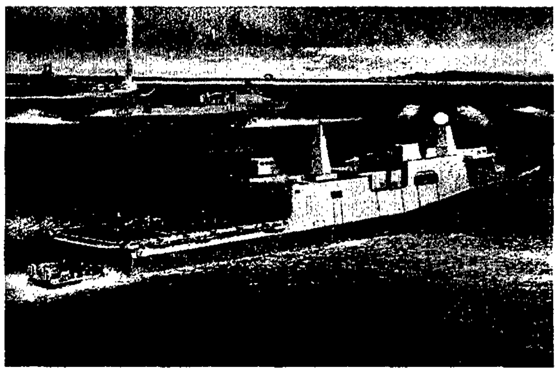

Figure 3-2. AEM/S Application to LPD17.

Another example of innovative topside design is the Low Observable Multi-function Stack (LMS) ATD which demonstrated technologies that address other dominate topside signature issues like exhaust system Infra-Red radiation and the RCS of HM&E items as well as incorporation of multi-function phased array SATCOM antennas into deckhouse structures. In particular the LMS project demonstrated two advanced exhaust suppresser systems that are enclosed in a low signature composite structure containing two embedded antenna systems that provide four SATCOM links in current use on Navy combatants. The concept for the LMS is shown in Figure 3-3. Figure 3-4 shows the LMS during recent at-sea testing in the Gulf of Mexico.

There are several additional ongoing developments that promise to provide topside design options. These include the Integrated VHF/UHF/L band multi-function antenna, S-band antenna development, and the Low Observable Integrated Deckhouse (LID) of the Platform Protection Future Naval Capability (FNC) project. All of these emerging topside technologies can be used to field new and modified combatants with greatly enhanced capabilities. One concept of how these emerging technologies could be used is shown in Figure 3-5.

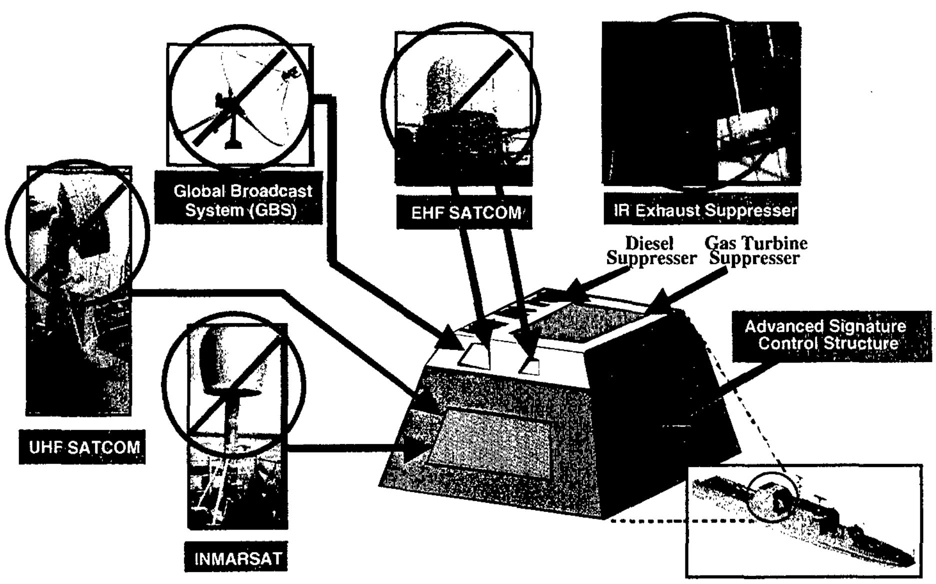

Figure 3-3. LMS Concept

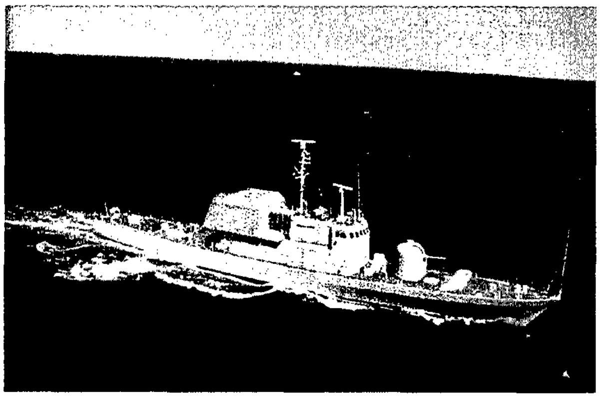

Figure 3-4. LMS At-Sea Test on RV Lauren

The concept for the Enhanced Capability DDG is based in a large part on taking advantage of the technologies that we have already developed in the S&T programs discussed above. The primary benefits of this concept are full network centric operations, reduced platform signature, and increased combat system effectiveness. Specifically this concept will:

- Improve theater Missile Defense capabilities by providing additional communication links for shared organic data and direct downlink from national assets.
- Improve Naval Fire Support capability by providing additional communication capability for UAV control and direct downlink from UAV and staring sensors.
- Improve Survivability through reduction of both RCS and IR signatures.
- Improve combat system effectiveness by reducing sensor blockage and maximizing system availability.

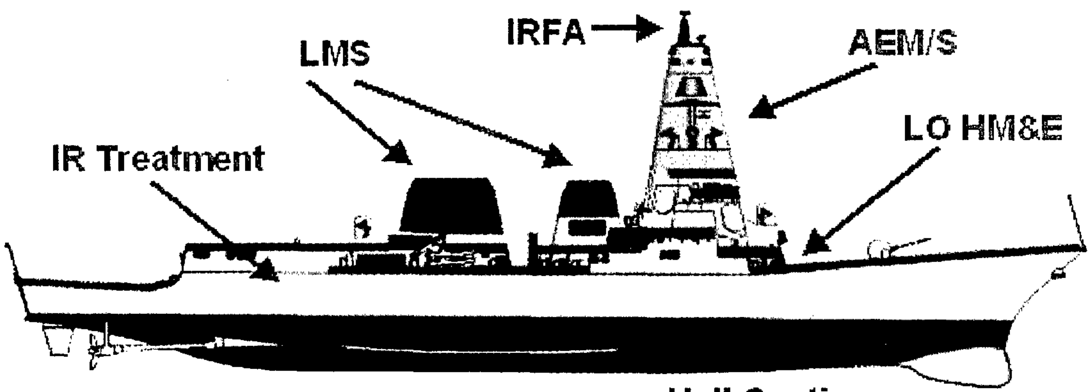

Figure 3-5. Enhanced Capability DDG 51 Concept

The technology basis for an enhanced capability DDG or the application of this technology to other platforms like the DD(X) has been or is being proven in the recent S&T developments. However, in many cases the technology is not ready for immediate incorporation into detailed ship designs. While individual ship programs are very interested in the capabilities that incorporation of these technologies can bring it is often difficult for individual programs to carry the necessary Engineering, Manufacturing and Development (EMD) efforts needed to increase the technical readiness levels. What is needed are coordinated EMD programs to bring these technologies options to the maturity necessary so that they can be included in detail design of ships. This can only be achieved with a balanced investment strategy that will be discussed later.

Another area that needs to be exploited for the Next Navy is that of advanced real time ship signature/emissions tactical decision aids. Current signature and emission modeling, prediction, and measurement capabilities can be extended in the near to mid term time frames to provide a tactical capability to Navy combatants that allow the fleet to take full advantage of the signature and aperture investments underway. Figure 3-6 provides a notional representation of how near real time ship signature assessments (acoustic and radar cross section) might be used to provide valuable tactical utility and

Figure 3-6. Simulated Mission Analysis Run Using Signature Predictions

vulnerability information to fleet operators. This capability could be introduced in steps starting with a near real time situational awareness tool and progressing to a fully integrated action and response system.

4.0 NAVY AFTER NEXT

The Navy After Next is represented by those capabilities to be realized beyond the current Future Year Defense Plan (FYDP) and out 15-30 years. It could be better described as the Navy's cutting edge research and technology investments studying completely different system architectures, ship and vehicle forms and functions and new ways of performing the known traditional missions as well as flexibility to execute the unknown future mission posture of the Naval forces.

Extensive function and system trade studies are critical to ensuring the most efficient investment strategy for the Navy After Next. These trade studies must consider current and future operational architectures of Naval and Joint operations, system performance requirements, signature requirements, topside integration technologies (as an element of the form and function changes to the platform), and cost. Although the future is always hard to predict with accuracy, it is relatively easy to envision the need for extensive technology and system trade studies related to the continued expansion of stealth in our military platforms and the still expanding capabilities realized through exploitation of the RF spectrum. While these two domains have appeared to be in conflict in the topside designs of recent ship designs, there is opportunity to investigate alternatives that can enable the synergistic cohabitation within the topside design.

Signature control for the Navy After Next will require innovative signature control strategies that allow the ship to remain effective in a constantly changing environment. These strategies must overcome the challenge of maintaining effectiveness while at the same time being robust in a shipboard environment, having minimal impact on other ship systems, and being low cost. In addition the signature control strategies for the Navy After Next must anticipate and counter ever evolving threat capabilities.

Historically the primary emphasis for ship topside signature control has been on Radar Cross Section (RCS) reduction in specific bands of the microwave spectrum. In more recent times there has been additional interest in Infrared (IR) signature control, mostly in the thermal bands. This relatively narrow focus was appropriately based on current threat capabilities as well as the cost and availability of technology solutions. As we look forward to the Navy After Next it is clear that ships will face increasingly sophisticated and capable threats. Not only will the threat performance capabilities in the spectral regions of current interest increase, but the threat capabilities will expand to cover more and more of the electromagnetic spectrum. In order to maintain effectiveness against these evolving threats, signature control technologies must have three inter-related and seemingly incompatible characteristics:

(1) Solutions with increased performance capability that is robust across a wide range of environmental conditions and across the range of anticipated ship operational evolutions

(2) Solutions that are compatible across the full spectrum of threats

(3) Solutions that are affordable in terms of initial cost and life cycle/ship impact costs

Navy After Next signature control solutions will need to take advantage of S&T innovations in materials and processes. These solutions will also require a willingness to re-visit current accepted tenants of signature control to allow tradeoffs among the wide range of requirements. For instance changing the approach to signature reduction in one spectral band might significantly open the design space in another spectral band.

From the perspective of Navy communications the goal is to provide Dynamic Interoperable Connectivity thus better isolating the physical hardware changes/updates from the functional changes/updates. The challenge of Dynamic Interoperable Connectivity includes:

- "Stove piped" communications systems.
- Non-interoperable protocols and data structures (e.g., JCTN/JDN/JPN interoperability & data "sharing" issues).
- Too much data push and too little ability to pull.
- Capacity limitations (i.e., not enough capacity to meet the needs of all users).
- Severe limitation by platform constraints (i.e., volume, weight, moment, cosite interference, and signature).
- Continually changing constraints (e.g., propagation, interference, QoS, . . .).
- Mandated lower life cycle costs and manpower requirements

The challenge is to provide Dynamic Interoperable Connectivity while meeting the challenges of Integrated Topside Design. The following sections provide several developments that will serve as the basis for the Navy After Next Investment that meets the increasing demand for Interoperable Connectivity while supporting Integrated Topside Design.

Communication System Common Framework

The Shipboard RF Distribution System of today severely limits Dynamic Interoperable Connectivity. It is the principal limitation to Dynamic Interoperable Connectivity. The RF Distribution System consists of stand-alone devices requiring switching, patching and cabling. Operator intensive actions are required to change configurations. It is manpower intensive with great potential for error. The Navy's most modern shipboard RF Distribution Systems are far from meeting the objectives of Dynamic Interoperable Connectivity. The RF Distribution System is physically large, heavy and expensive with limited capacity to accommodate future growth and technology insertion. There are limits to the number of circuits that can be connected to an individual antenna. For this reason the Shipboard RF Distribution System of today not only limits Dynamic Interoperable Connectivity, but severely limits the ability of communication antenna systems to meet the objectives of the Integrated Topside Design. The following figures are representative of a shipboard RF Distribution System.

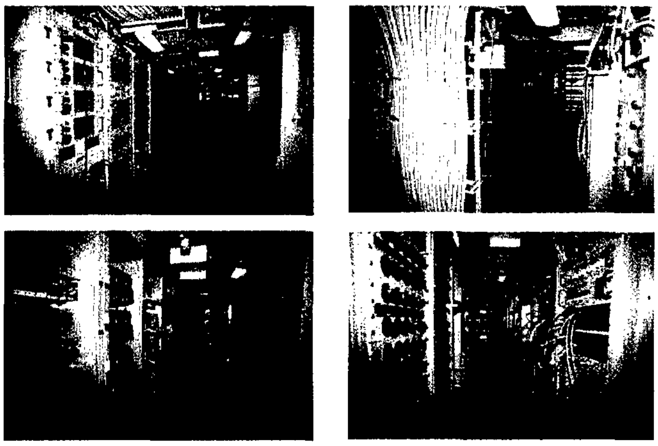

Figure 4-1. Today's Shipboard RF Distribution System.

A Communication System Common Framework is needed. A pictorial of the Communication System Common Framework is depicted in the accompanying Figure 4-2. The system concept for this Framework includes an open architecture, common interfaces, individually addressable modules, an Internet Protocol based controller and enhanced interference mitigation. Each of these attributes are discussed in the following:

OPEN ARCHITECTURE

The open architecture expands the software radio philosophy of the Digital Modular Radio (DMR) and Joint Tactical Radio System (JTRS) throughout the entire RF Distribution System. A general architecture is envisioned of distinct functions. All RF Distribution Systems perform a set of common functions (e.g., filtering, amplification, conversion, . . .). The general architecture would be a decomposition of a set of individual, orthogonal objects that can be assembled to meet a specific set of RF Distribution System requirements. Multiple vendors could provide the individual components of a RF Distribution System, which would lead to an increase in competition and potential decrease in over-all cost. The Framework would be updateable with maturing technologies. It would not be necessary to swap out entire systems for upgrades.

The Communication System Common Framework provides a more affordable, open architecture that can lead to improved interoperability with Joint and Coalition forces. Incremental investment strategies are possible.

COMMON INTERFACES

Common interfaces would include taking military RF frequencies and converting them to COTS (i.e., commercial off-the-shelf) intermediate frequencies (IFs). It would also require the use of Ethernet control protocols. This would allow leverage of commercial developments.

INDIVIDUALLY ADDRESSABLE MODULES

A dynamically reconfigurable physical layer for all subsystems is achievable with individually addressable modules. Dynamic reconfiguration is key to Dynamic Interoperable Connectivity. With this inherent flexibility it may be possible to reduce the number of required circuits. This would lead to a decrease in the requirements on topside antennas.

INTERNET PROTOCOL (IP) BASED CONTROLLER

An IP Based Controller enables automated diagnostics and recording. Automatic and remote update of software is possible. The RF Distribution Systems of a Battle Group would be remotely accessible with possibly a web site for each shipboard system. Each device is then a web page. It would be possible to reconfigure the physical layer of an entire Battle Group in response to changing C4ISR requirements. Communication would not be limited by quasi-static communication plans.

ENHANCED INTERFERENCE MITIGATION

This is key to increasing the number of circuits that can be supported by an individual antenna system. This has a direct impact on the reduction in the number of topside antenna systems.

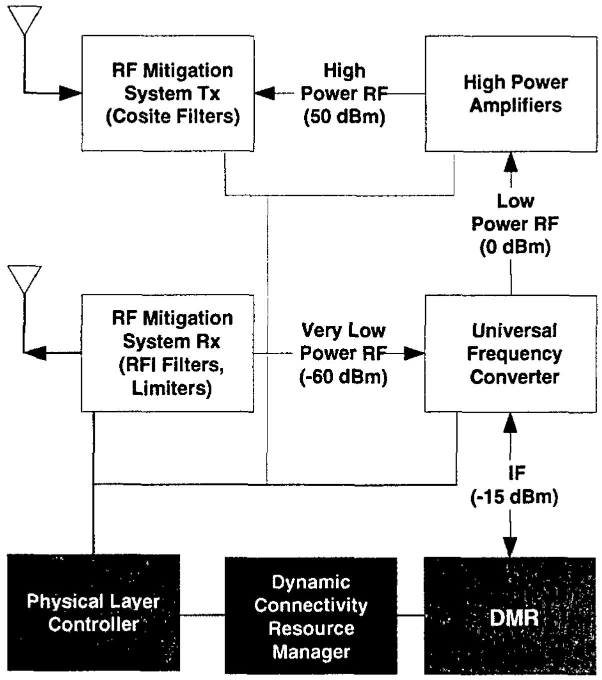

Figure 4-2. Communication System Common Framework.

The technical challenge to developing a Communication System Common Framework is considerable and will include technologies such as system-on-a-chip, low cost phased array architectures and active EMI cancellation to name a few.

Exploitation of Higher Frequency, High Capacity Links

The emphasis on Network Centric Operations guarantees additional growth in the demand for communication capacity. This can force larger numbers of antenna systems on Navy ships, where SATCOM antennas already dominate ship's deck space. An approach is required that provides increased connectivity to the Fleet while supporting Integrated Topside Design. Two developments are proposed.

In the first development, terrestrial links would be increased in capacity. Present terrestrial links are limited in capacity. HF surface wave communications has been demonstrated up to 64 Kbps. UHF Line-of-Sight communications has been demonstrated up to 3 Mbps. Terrestrial links can be increased to over 300 Mbps by leveraging the higher frequency bands and technology of military data links. Ku-band links can be leveraged as part of a Battle Force Communication Network. The Ku-band links could be formed into a microwave network providing very high capacity within the Battle Group. Through the use of relays, the microwave network could be extended in range.

In the second development increased high data rate SATCOM would be provided to the Fleet. In the commercial world, business plans are emphasizing the migration of SATCOM to the higher frequencies with more capable satellites for increased data rate to the user. The Navy will by economic necessity follow a similar migration. This migration includes the Wideband Gapfiller System (WGS) at Ku-band and the Global Broadcast System (GBS) at K-band. These military systems should be augmented with emerging commercial capabilities at Ku and K/Ka-band. As depicted in the following Figure 4-3, these developments provide the potential for a considerable increase in capacity to the Battle Group.

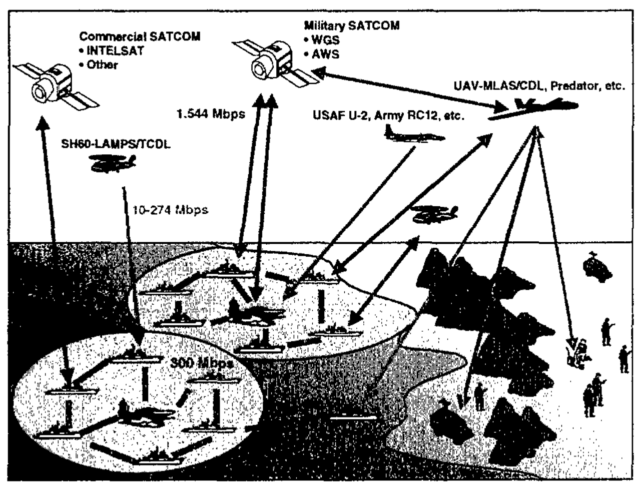

Figure 4-3. High Capacity Battle Group Network.

The movement to higher frequencies reduces the requirements for physically large antenna structures. Antenna performance is directly related to frequency. As the frequency of a given sized antenna is increased, its performance is increased. In addition, the modern satellites in the Ku-band and K/Ka-bands are more capable, reducing the requirements on the terrestrial user. Both of these factors lead to smaller sized antennas with higher capacity. Thus, smaller antennas could replace the current physically large SATCOM antennas with increased capacity. In addition, multi-function phased array technologies at these higher frequencies can be used to mitigate the platform integration issues of integrated topside design. The high capacity battle group network of the figure above could be implemented using multiple beam Ku-band phased arrays. A single, multiple beam Ku-band phased array would provide high capacity connectivity to military and commercial SATCOM, military data links and a microwave network. Finally, this increase in terrestrial capacity should reduce the requirement on the lower frequencies terrestrial links. This could lead in a reduction in the number of antennas systems required to support these lower frequency bands.

An investment in the exploitation of higher frequency, high capacity links is key to providing the increased capacity demanded by the Fleet, but also in meeting the challenge of integrated topside design.

Affordable Multi-function Phased Arrays

Recently the Navy senior leadership has taken a very positive and active role in developing and aligning programmatics to an overall aperture strategy. This RF Aperture strategy has been critical for the transition of Navy ships from platforms with multiple RF systems of single antennas supporting single functions (i.e., radar, Electronic Warfare, Information Warfare, Communications) to multi-function, multi-frequency shared apertures. The strategy addresses two major issues, flexibility in spectrum exploitation and affordability. The flexibility in the RF spectrum usage of the ship/battle force is inherent in the application of an RF Resource Controller that allocates in real-time, the multi-function sub array elements to the necessary shipboard functions. The affordability aspects of planar array technology, which is necessary for ship integration but currently expensive with the moderate costs of the elements which could number in the many 1,000's per array, is realized again through multi-functionality. A planar array per function would be inefficient and unaffordable. Partitionable wide-band sub arrays will allow for some amortization of the higher cost array across the many functions it now provides. These elements of the aperture strategy are fundamental to meeting the challenge of Integrated Topside Design.

At this time the investment emphasis has been on the development of multi-function, extremely wideband arrays. As an example, the concept is a single extremely wideband array with multiple beams supporting all RF functions in the 1 to 5 GHz band thus significantly reducing the number of topside RF apertures. Some of the RF functions such as radar and electronic warfare require positions high in the superstructure due to horizon line-of-sight limitations, while other functions, such as SATCOM do not. All requirements would have to be satisfied in a single array concept. A possible, earlier spin-off design concept could have multiple phased array antennas covering the band. As an example, four 40% wideband antennas are required to cover a 1 to 5 GHz band. This wideband, multiple array concept may actually provide more flexibility to achieving topside integration. A set of 40% frequency bandwidth arrays vice a single 5:1 bandwidth frequency array may serve early transitions.

Multiple, wideband array antennas can be designed to meet low signature goals. With increasing bandwidth, signature control becomes much more difficult to achieve.

Using a single, extremely wideband array might have economies of scale. The argument is that the cost of individual elements will be less because all of the elements are the same. Using a wideband, multiple array design, the architecture is the same for all of the apertures. There are economies of scale when there is a common architecture. Companies have shown economies of scale when there is a common architecture through the use of flexible assembly lines.

It is well known how to build arrays. Phased arrays have not been cost-effective for most applications. An important consideration is how phased array systems become affordable. GPS systems became affordable once Japanese consumers wanted GPS systems in their cars. Due to the commercial cellular phone/wireless communications industry, arrays developed in the L/S frequency bands can achieve affordability using readily available discrete components. Arrays in the Ku, K, and Ka frequency bands have similar potential with the drives for commercial systems in these bands. Where there is little to no commercial interest, such as Q-band, systems suffer from problems of component availability, cost, and performance due to a lack of interest from producers. Multi-function phased arrays are key to Integrated Topside Design. However, in order to ensure the shipboard implementation of this important technology the investment in multi-function phased arrays technology needs to focus on affordability.

As previously stated, extensive system trade studies are critical to ensuring the "best investment strategy" for the Navy After Next. These trade studies must consider system performance requirements, signature requirements, topside integration issues, and cost. A strong case can be made for investing in a common RF framework for ships, for exploiting higher frequency, higher capacity links on ships and in battle groups and finally the advancement of wideband array technology to gain control of the spectrum and make it a force multiplier. New ship concepts and force structures assessments should be evaluating applicability of these technologies to achieving their final requirement goals in our Navy After Next.

5.0 INVESTMENT STRATEGY

“A balanced investment strategy is the best investment strategy”. "Build a little-test a little works for the Navy”. Today’s acquisition philosophy/structure is already risk adverse and will continue to be in the near future due to ever pressing fiscal constraints. An evolutionary development of ships’ integrated topsides will lead to a predictable end state. It allows for “buy in” by the Navy community of stakeholders (ONR, OPNAV, SYSCOM, and Fleet) with measurable progress through fielding capabilities along the path. Investment strategies that only resource the end state at the expense of all other items on the evolutionary path is very high risk. A technological failure of a critical path item related to the end state initiative with no backup could set the Navy back in topside technology implementation and therefore fielded warfare capability. In addition, a failure of transition due to misalignment with the other critical stakeholders necessary to transition the capability in significant numbers to achieve “warfare capability at sea” could jeopardize an end state success.

The balanced investment strategy must be evolutionary in its approach and focus. It must be predicated on a balance of investments. These investments can be described in terms of near-term, mid-term and long-term. Funded and reprogramming efforts are the focus of the near-term. Mid-term focuses on technologies that are either in advanced development or are candidates with some investment for advanced development and require engineering development. Exploratory Development is the focus of the long-term. For the purpose of this discussion, near-term relates to the Current Navy, mid-term relates to the Next Navy, and long-term relates to the Navy After Next.

The "balanced investment strategy" is representative of the best development strategy for both new construction and the fleet modernization program. This strategy supports full Network Centric Warfare capabilities, combat system performance capabilities, and low signature HM&E concepts. This strategy would consider the investment of multiple sponsors and ensures affordable success by exploiting commercial developments. It is only with the balanced strategy approach that the needed topside technologies would be viable. Table 5-1 lists some of the technologies that should be exploited for the various categories Navies.

The strategy must address the fielding plan for next generation topside systems. The Fleet is composed of approximately 330 ships, which make up 12 Carrier Battle Groups and 12 Amphibious Ready Groups. Approximately 5 pairs (CV/L) are readied for deployment in any one year. It is unrealistic to expect the fleet to wait for next generation topside systems via the slow introduction of next generation ship acquisition timelines (i.e., DD(X), CVNX1).

The mix of RF systems comprising the war fighting capability of the Battle Force must be introduced not only via high-end new ship/RF architectures, but also via RF system upgrades to existing ships of the Fleet (i.e., DDG 51, CG 47, LHD, LHA, CVN). These ships will exist in significant numbers through the middle of the next century. It is unlikely that currently envisioned end states for RF services would be fiscally viable for these current ship architectures via the Fleet Modernization Program (FMP). These legacy ships need simpler, quicker to market, and more flexible RF systems that still have some of the positive benefits of the advancing technology base.

A balanced approach must recognize and deliver interim products to integrate into the existing fleet architectures. These products must be paced with combat system upgrades using a similar strategy (e.g., Advanced Integrated Electronic Warfare System, Multi-Function Radar) for common integration and fielding [Mearns and Stetson 1999]. The envisioned end state will be realized by building off this mid-term investment. This will provide industrial base maturation, fleet experience in expansion of the RF and low observability domains to satisfy new operational needs, and acquisition experience in multi-function system procurements and SCN driven packages and associated life cycle costs (LCC). The majority of the investment burden must be borne by this mid-term investment for the Next Navy.

Finally, a small but no less important investment must be supported for the long-term, high-risk/high-payoff technology domain for the Navy After Next. Here new constructs for the foundational architectures of the Naval force can be experimented with, evaluated for war fighting value and can be used to set the "goal" for technology roadmap developments. Having this goal is very important to act as a compass direction for what can be realized (the art of the possible) as the current acquisition programs-of-record evolve in execution due to performance challenges, economic realities and political pressures.

"If you don't know where you're going, any road will get you there". These long-term investments will establish the boundary conditions for the development of the next acquisition program.

Current Navy	Next Navy	Navy After Next
Eng Design Tools	Composite Materials	Wide Band Gap Semi-Conductors
Eng Design Data Bases	Planar Array Antennas	Multi-Function Apertures
	Radar Absorptive Structures	Directed Energy Weapons
	IR Signature Control	Autonomous Operations
Cooperative Engagements	Cooperative Deployment	Cooperative Force Structures
Single Integrated Picture	Common Operating Pictures	Collaboratively Controled Env
Network Centric Architectures	Open Architectures	Morphological Structures
Minituration	Consolidation	Nano-Devices
	Signature Tactical Decision Aid	Advanced Signature Control

Table 5-1 Exploitable Technologies for Enhancing Ship Topsides

6.0 CONCLUSIONS

Historically, warfighting effectiveness has been the primary driver for advances in the implementation and arrangement of topside systems on U.S. Navy combatants [Tibbitts-Baron 1998]. That observation is still valid today and will be into the foreseeable future. The role and the challenge to the Navy's topside design community is to simultaneously achieve this increased effectiveness across three separate fronts:

- Maintaining the combat effectiveness of our current Navy
- Preparing for the modernization of our next generation Navy
- Developing the topside technology to be implemented in the Navy after next

As a group, we must develop, design and maintain our ships and systems for the evolutionary incorporation of emerging technologies as they are developed as well as identifying and exploiting the revolutionary innovations necessary for step-function increases in capability. Success in these areas requires a balanced investment strategy that considers the slow introduction of next generation ship acquisition timelines coupled with the cautious and seemingly unavoidable hesitance for the introduction of new technology that results once a ship acquisition program has begun. A balanced approach must recognize and deliver interim products to integrate into the existing fleet architectures. These ships will exist in significant numbers through the middle of this century and it is unrealistic and perhaps negligent to delay the insertion of this technology until new ship classes reach the fleet.

A balanced investment approach needs to incorporate both the evolutionary path of 'sustaining' technology developments as well as the revolutionary step towards 'disruptive' technology insertion [Martin 2000]. Critical to either of these approaches is a greater emphasis on experimentation and demonstration. There has been a lot of interest on experimentation associated with the call to 'transform' the military [IDA's Joint Advanced Warfighting Program]. A definition is offered below:

experimentation: The process of exploring innovative *technologies*, especially to assess their feasibility, evaluate their utility, or determine their limits.

In the topside technology area, there is a need for systematic and continuously planned, funded and supported at-sea technology demonstrations. This support needs to be across the Navy organizational spectrum and include the requirements, acquisition, technology and operations codes within OPNAV, NAVSEA, SPAWAR, NAVAIR, ONR and the fleet. These demonstrations need to support technology solutions that are applicable across multiple ship platforms. Demonstrations are needed not only to mitigate the risks associated with the eventual adoption of advanced technology by new ship programs but also to provide the legacy fleet with some of the positive benefits of the advancing technology base. The demonstration of developing technologies on a fleet asset pose specific risks (both technical and financial). Those risks need to be acknowledged, accepted and budgeted in order to accelerate the adoption of warfighting benefits to the fleet.

As discussed in this paper, the topside design community has done a good job of embracing the tenets of Total Ship Systems Engineering and integrated topside design practices. Perhaps we've been less diligent in translating that integrated approach to the planning and roadmapping necessary to coordinate our investments across the many technical areas that make-up the topside. This coordination is essential to continue our successes in either evolving or revolutionizing the topsides of our future fleets. It is a large and diverse community and we need to conscientiously work towards improving our communication, needs and priorities. There is an opportunity for better coordination between the many organizations that affect and influence the topside design process. We need to get off the merry-go-round every once in a while and ask ourselves questions.

Do we understand the requirement needs for future ships in time to plan S&T needs?

Are our current modeling and simulation tools sufficient? Do today's EM engineering tools adequately handle the performance and isolation issues associated with the unprecedented trend towards integrated antennas? Will those tools be able to account for the arrangement and distribution of topside systems at a *fleet level* as opposed to a *ship level* as envisioned in a truly network centric fleet? Are our signature prediction codes adequate to predict the ever-decreasing signature requirements of the future? Can we adequately predict the performance of advanced composite structures to the harsh environmental and combat loads of a surface ship?

Is there a need for a more diverse investment in shared aperture technology? Does the current interest in very wideband arrays make sense if the future fleet make-up consists of smaller, cheaper, network-linked, littoral craft?

Do we need to more strongly pursue autonomously operated surface vehicles? What is a littoral support craft? How will future gun systems influence topside design? What is stealthy enough? Why?

Only by working together as a total ship community, will we be able to get the right answers.

REFERENCES

CDR Mary Martin, USN, "Revolutionary Innovation in a Fiscally Constrained Environment", Naval Engineers Journal, July 2000.

"What Does 'Military Experimentation' Really Mean?", one of a series of Occasional Papers prepared by IDA's Joint Advanced Warfighting Program (JAWP). An extract of an extensive body of work originally funded by the Deputy Director for Wargaming, Simulation and Assessment; Director for Force Structure, Resources and Assessment (J-8).

P. E. Law, Jr., *Shipboard Antennas*, Artech House, Dedham, MA, 1983.

P. E. Law, Jr., *Shipboard Electromagnetics*, Artech House, Norwood, MA, 1987.

N. T. Baron and D. R. Cebulski, "EMI – The Enemy Within," *Naval Engineers Journal*, March 1992, Volume 104, Number 2, pp.69-80.

P. Bobrowich and B. Douglas, "Mitigation of Shipboard Induced Degradation on LHD 5 Combat System Performance," Association of Scientists and Engineers of the Naval Sea Systems Command, *29th Annual Technical Symposium, May 1992 Symposium Record.*

Capt. B. Tibbitts, USN (Ret.) and N. T. Baron, "Topside Design of Warships: A 100 Year Perspective," From *Research to Reality In Ship Systems Engineering Symposium Proceedings*, American Society of Naval Engineers, September 1998, pp. 57-75

Rockway, J.W. et al., "EM Design Technology for Topside Antenna System Integration," *Naval Engineers Journal*, Vol. 113, No. 1, Winter 2001.

Mearns D. Michael, Stetson Neal K., " Integrated Topside Design," *Naval Surface Warfare Center Dahlgren Division Technical Digest,* 1999.

Ames, Robert M., Richard T. Van Eseltine, "Architecture for Multidiscipline Integration of Analyses in a Common Product Model Environment for LHA(R) Topside," 2001 Electromagnetic Code Consortium (EMCC) Annual Meeting, Kauai, Hawaii, 28 May – 1 June.

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