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Developing Reconfigurable Command Spaces for the *Ford*-Class Aircraft Carriers

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ABSTRACT

The U.S. Navy is currently in the process of designing and constructing the first new class of aircraft carriers in half a century and the last of this class will be in service into the next century. As a result of the exponentially increasing capability being brought forth in the electronics industry and the ever-changing warfighting and mission capability demands, the aircraft carrier community has been pursuing ways of maximizing the flexibility of these ships to adapt to the demands of their service, maintain pace with technology advances, and remain cost effective in both acquisition and life cycle.

One area in which the aircraft carrier community is achieving this flexibility is in the development of reconfigurable command spaces. The command spaces for the *Ford* class are being designed with the expectation that change will come many times over on a ship with a 50-year service life. This paper will discuss the flexible infrastructure design approach being utilized and its associated goals and benefits.

INTRODUCTION

Aircraft carriers provide the United States with a warfighting capability unlike any other in the world. These ships influence the actions and behavior of other nations just by their presence and enable the United States to bring its warfighting capability directly to where it is needed, projecting power across the globe. They provide a credible, sustainable, independent forward presence during peacetime without access to land bases and carry the war to the enemy when necessity dictates it. These ships, by design, provide an unparalleled flexibility and an ability to reconfigure the balance of power solely based upon how they are positioned.

It is recognized today, however, that the future class of aircraft carriers, the *Ford* class, will also need to be capable of carrying out a broader set of missions while being able to incorporate an ability to defend itself in hostile environments of varying and continually changing technological capability and threats. In addition, it will also be necessary to apply the improved design features of this class to the existing *Nimitz*-class aircraft carriers, as the last of this class, USS *George H.W. Bush* (CVN 77), has just been delivered to the Fleet with an expected service life of 50 years; and this class will comprise the majority of our nation's sea-based aviation strike capability for the next three decades.

This paper will discuss one approach being taken by the Future Carriers Program Office to enable the *Nimitz*- and *Ford*-class ships, which will be in service for the next 100 years, to maintain their viability and mission capability throughout that service life. This approach is the utilization of a flexible infrastructure concept designed to provide a means of enabling greater mission flexibility and an ability to address technology maturation, enhancements, and obsolescence. It enables the flexibility and growth potential characteristics identified in the platform's Mission Needs Statement of having the versatility to support current and future sea-based aircraft, to perform simultaneous multi-mission tasking, and to readily adapt to changing operational needs.

Key to this approach for the Navy of today is to reduce the acquisition and life cycle costs in both design and construction, as well as to establish a cost-effective method in which the ship, in this case the command spaces of the ship, can be reconfigured and upgraded with reduced disruption and without costly hot work. Utilizing the flexible infrastructure concept will mitigate the need for the physical cutting and welding of equipment foundations to make changes within a command space, a labor-intensive and time-consuming process. Also associated with this conventional approach to reconfiguration or modernizing the capability within a command space of a ship is the labor and cost of rearranging the infrastructure of HVAC [Heating, Ventilation, and Air Conditioning], power, cabling, and the services the ship provides to that space and the contained equipment.

OPERATIONAL REQUIREMENTS

With the end of the Cold War and the evolving capabilities of both our warfighting capability and the capabilities and tactics of our adversaries, the operational missions for aircraft carriers have broadened and the self-defense requirements have become more complex. When the Future Aircraft Carriers Program was established, a set of operational requirements were defined by the Office of the Chief of Naval Operations staff to identify the capabilities that the program would deliver to the Fleet and to address these broadened needs.

Included in the requirements was the recognition that during its service life, the ship will need to accommodate special or changing missions, not unlike the recent diversion of the USS *Carl Vinson* (CVN 70) to Haiti to execute humanitarian missions, embarking organizations, such as Special Operations Forces, to address specific, unique missions and doing so while being designed to manage life cycle costs effectively.

Use of reconfigurable spaces enables efficient accommodation of such missions; allows for incorporation of emerging processing, communication, and data technologies in a minimally disruptive manner; and also promotes utilization of commonality approaches with other ship designs.

RECONFIGURABLE SPACES USING A FLEXIBLE INFRASTRUCTURE CONCEPT

To meet the reconfigurable space requirements, the Navy engineering community and its industry partners needed to design a means by which this requirement would be accomplished while trying to address both acquisition and life cycle cost objectives. Additionally, the solution needed to accommodate the Navy’s existing warfare systems acquisition approach and infrastructure.

The solution mutually decided upon was to develop a flexible infrastructure to make the command and warfare system spaces within the ship able to adjust to the changing requirements of the functions that may be performed within that space and equipment configurations that would be used to conduct those functions. Flexible infrastructure is the Navy’s approach to meet Fleet needs by providing for mission flexibility, without requiring structural rearrangements and service modifications, at a reduced cost to the Navy.

Select ship spaces will be outfitted with tracks on the deck, bulkheads, and in the overheads for the outfitting of items such as speakers, lights, electrical receptacles, and monitors. This will enable the Navy to relocate consoles and cabinets in the future as the space will accommodate it. The deck support structure was designed to accommodate worst case loading, using previous aircraft carrier information as a baseline. Ventilation and wire ways will be run underneath a false deck so that ventilation and wiring can be reconfigured to accommodate changing technology and space arrangements. Additionally, the main HVAC systems reside in adjacent spaces, which do not require modification when the space is reconfigured and which provide a drastic reduction in “airborne” noise in the command and control spaces where this approach is utilized.

As a result of the incorporation of this infrastructure concept, these spaces will save the Navy significant costs over the life of a ship as new missions require space reconfiguration or new technology calls for the replacement of existing equipment.

GOALS FOR FLEXIBLE INFRASTRUCTURE

The flexible infrastructure concept is justified by the changing mission needs of the Navy and the requirement to respond quickly and effectively to those changing needs. The "permanent" nature of infrastructure installations on current carriers makes it difficult to respond quickly to these changing mission needs. The nature of the proposed changes would be to move away from "permanent" installations and toward "flexible" solutions that support reconfiguration needs. These changes must occur without allowing the ship's capabilities to be compromised.

The flexible infrastructure system is designed to address the requirements to reconfigure designated spaces and specific goals listed below:

- Provide a cost- and time-efficient means to remove and install equipment (primarily associated with evolving technologies tailored to specific missions) through the ship construction period and throughout the ship's life cycle; e.g., modernization/Refueling Complex Overhaul (RCOH).
- Support the capability of a rapid refresh cycle and allow the frequent reuse of equipment foundations via adaptor plates, where possible.
- Support equipment relocation and installation, providing the ship with the ability to support changing mission requirements throughout the ship's life cycle.
- Minimize the need for disruptive and costly hot work. Hot work is defined as any spark- or flame-producing process associated with the construction of the ship. Minimizing it will reduce the need for numerous qualifications and the associated training costs, eliminate associated watch and engineering support services, minimize inspections, avoid potential environmental and health issues, avoid equipment protection costs, and avoid potential rework to coating systems and insulation due to smoke or direct damage.
- Provide a method for arrangement layouts and interface adapter prefabrication to occur without concern about lining up to the existing ship's structure. Flexible infrastructure compartments will be installed with the same track orientation and spacing to enable consistent reconfiguring throughout all related spaces.

Benefits expected include the following:

- Accommodate Navy Participating Acquisition Resource Manager development cycles, technology insertion, modernization, and obsolescence/commercial, off-the-shelf refresh without specific accommodation for specific aircraft carrier configurations and schedules.
- Maximize time for technology development prior to equipment installation during new construction outfitting.
- Ease compartment reconfiguration to support changing missions and life cycle refresh of electronic components.
- During construction,
  - Complements design budget government-furnished information/government-furnished equipment approach
  - May reduce costs by using system installation teams
  - Reduces cost and schedule impacts from contract modifications/change orders, rework, and typical disruption and churn
  - Reduces complexity of balancing ship cost/schedule risk with warfare system risks
  - Expected to be faster to install than legacy infrastructure
    - Reduces space layout engineering
    - Provides tolerance to address deck leveling issues
    - Flexible infrastructure drawings may be reusable for other aircraft carriers
    - Accommodates design improvements for better Human Systems Integration/Human Machine Interface configurations to enable more effective warfighter performance

- In support of system test, the potential benefits of utilizing flexible infrastructure during system-level development include the ability to establish land-based test facilities that can accommodate system configurations as they would be installed on ships while maintaining the ability to quickly reconfigure the test facility for its next test event of a different ship configuration. When modernization occurs or new system elements are introduced, the test facility can quickly be reconfigured to accommodate the change and enable integrated testing. In addition, the configuration can replicate the installed ship configuration in the land-based test environment thereby providing a higher degree of certainty that the system will work within the platform and have minimal impact to other mission areas. These characteristics would be of benefit and provide potential savings for both new-construction application and modernization requiring installation post ship delivery or during maintenance availabilities because key stage testing can be conducted within the comparable land-based test environment prior to delivery to the ship.
- During life cycle,
  - Provides mission flexibility
  - Allows rapid system upgrades
  - Supports manpower/labor reductions
  - May reduce the life cycle weight gain that typically occurs due to practice of not removing remaining unused material (piping/wiring/cabling)
- Flexible infrastructure components can be selected and/or combined for utilization in specific spaces based upon the expected uses of the spaces, the maturity of system designs, and installation lessons learned.
- Potential issues to be mitigated include the following:
  - Initial acquisition cost may be higher than legacy infrastructure
  - Requires logistics documentation and training for ship's forces and installation teams to utilize properly
  - A logistics strategy is required for parts and a maintenance/replacement approach defined for items that may need replacement during its life cycle, such as decking material.

BUSINESS CASE ANALYSIS

To develop confidence in the concept of utilizing a flexible infrastructure approach and to assess the acquisition cost estimates and total life cycle cost impacts, Puget Sound Naval Shipyard, Detachment Boston, was commissioned to perform a business case analysis to assist in the decision for application on the Future Carriers Program.

In performing the business case analysis, a business approach was taken and USS *Gerald R. Ford* (CVN 78) was treated as a capital investment in which the modular infrastructure approach was compared to a baseline (conventional) approach utilized on a current *Nimitz*-class aircraft carrier. The analysis estimated the cost of the two approaches over the expected 50-year life cycle of the CVN 78 ship accounting for the original acquisition/ construction cost, costs associated with a major RCOH with a full reconfiguration, two Drydocking Planned Incremental Availabilities with full reconfigurations, eight Planned Incremental Availabilities with partial reconfigurations, and disposal costs consisting of complete removal of equipment.

The results estimated the total acquisition costs of both the conventional and modular configurations to be approximately equal (within the 10-percent fidelity of the model). Material costs for the modular configurations increased significantly but were offset by significantly reduced labor costs. Potential cost savings were identified in the full reconfiguration of the space during associated events at about 50 to 57 percent, with modest material cost increases and dramatic labor cost decreases, mainly associated with the elimination of hot work and greatly reduced HVAC reconfiguration costs in the modular configuration. Similar results were found in analysis of the partial reconfigurations. Potential cost savings of 22 to 50 percent were identified for the modular configuration in the disposal phase in which complete equipment removal was performed and structural and HVAC labor costs were greatly reduced. The bottom line of the analysis was that implementing a flexible infrastructure approach for the warfare system spaces of the type modeled was basically a cost-neutral effort during ship procurement and yielded anticipated savings during the life cycle modernization events. This was an important validation of the approach as current *Ford*-class aircraft carriers are cost-capped ships at the congressional level, and procurement costs are very strictly managed.

FLEXIBLE INFRASTRUCTURE COMPONENTS

Supported by the independent business case analysis, the Navy and Northrop Grumman Shipbuilding, Newport News, have proceeded to develop and mature the infrastructure components required to support the flexible infrastructure of the warfare system spaces. The flexible infrastructure is designed to be a system of integrated components, which permits interchanging and rearranging of components within a space to meet ship-specific missions. Provided in the following is a summary of technical characteristics of those components.

Decking Components

The decking components consist of high track elements, low track elements, deck tiles, track covers, and high track cross braces. These components, when installed as a system, provide a means by which equipment can be mounted in any desired arrangement, enables heating and cooling throughout the space without special configurations, and allows power and cabling to be routed as needed throughout the space to support the equipment needs.

TRACK SYSTEM

The deck track elements are comprised of raised tracks located at predetermined increments to maximize arrangements of equipment in these spaces. The track system provides a walking surface and a grid for attaching equipment, as well as space underneath for electrical service; in the case of the high deck track, a space for ventilation circulation is also provided.

DECK TILES, TRACK COVERS, HIGH TRACK CROSS BRACES

The deck elements are comprised of deck tiles, high track cross-braces, track covers, and the ventilation return plenum. The deck tiles fill in the space between the deck tracks, provide a walking area, and serve as the top of the HVAC deck plenum. The track covers hold the tiles in place and keep foreign materials from entering into the track profile.

The track cover is an extruded vinyl material that fits into the track profile and laps an undercut area of the deck tile to provide a flush surface. The track cover is provided in 10-foot lengths but may be cut to suit equipment and furnishing footprints. It is connected to the track using two button head cap screws at each end of the cross-brace. High track cross-braces are not required for structural purposes but may be included with high deck track to maintain track-to-track alignment.

Overhead Components

The overhead components consist of overhead track elements, modular ceiling tiles, ventilation grilles, ventilation supply diffusers, and ceiling tile lighting fixtures. These components, when installed as a system, provide a means by which cooling can be provided throughout the space, targeting equipment-specific needs without special configurations, as well as positioning lighting sources to best satisfy illumination needs. It also provides attachment locations for modular bulkheads, portable stanchions, miscellaneous equipment, and equipment interface adapters.

OVERHEAD EQUIPMENT MOUNTING SYSTEM

The overhead track attaches to the underside of stiffeners or pedestal assembly and provides a level mounting surface parallel to the deck track. The overhead track is built from sections no greater than 80 inches in length. These sections span lengths no greater than 77 inches with 1½-inch overhangs on each end. The overhead track is connected to the stiffeners or pedestal assembly using a drilled and tapped attachment adapter, machined spool piece, and standard fasteners at each end. The overhead track grid matches the deck track grid except that the forward and aft spacing is one track per every 24 inches.

Modular ceiling tiles fit between overhead tracks, and these tiles are secured to the overhead beam flange. Each modular ceiling tile will have the ability to be removed individually. Each tile will be provided with an open/close grommet for cable and connection passage. The acoustic ceiling tiles create a boundary between the manned compartment below and the HVAC plenum above. The tile is 0.04 perforated aluminum sheet (50-percent perforation coverage) with a baked enamel paint finish on the outer surface. Inside the tile has a core of lightweight insulation. The dimensions of a standard ceiling tile are 22-3/8 inches wide, 36 inches long, and 3/4 inches high. Non-standard ceiling tiles are installed in 6-inch-long increments. Each tile has an open/close grommet for the lighting cable and connector to pass through. Ventilation grilles and ventilation supply diffusers are incorporated into tiles as required, meeting ventilation requirements. A ceiling tile lighting fixture is utilized to meet lighting requirements.

Bulkhead Components

The bulkhead components consist of track elements and fittings that can be mounted on the permanent, fixed bulkheads, as well as modular bulkheads that can be installed within spaces by attaching to the deck and overhead track components. These components, when installed, allow for flexible equipment installation, such as video displays and automated status boards.

BULKHEAD TRACK

The bulkhead track is mechanically fastened using welding studs attached to the bulkhead. The bulkhead track is installed onto the welding studs and spaced vertically at standard intervals around the perimeter of the modular compartment. The bulkhead track fittings can be located at any position along their track’s length as long as the fitting does not cantilever beyond the track edge or span gaps in the strut and as long as permissible loading parameters are met. If the equipment cannot support the bulkhead grid system then an interface adapter will have to be designed to adapt the equipment bolting pattern to one supported by the grid.

MODULAR BULKHEADS

In cases where a space may be desired to be subdivided within the structural limits of the Decision Center spaces, modular bulkheads can be utilized. The bulkhead panels will be of rigid, lightweight construction. Bulkhead panels will be designed and constructed in accordance with marine industry standards for fire, smoke, toxicity, and hazardous material content. Material options include composite and/or honeycomb configurations.

Ship Services Components

The flexible infrastructure system must enable access to and utilization of ship services, including HVAC, power and lighting, and cable and wiring distribution systems. To allow the spaces to be configured or reconfigured without labor-intensive installation processes, ship services must be accessible and able to be relocated to satisfy the warfare systems equipment needs of the configuration. Within the capacity designed into the space for cooling, power, and connectivity, ship services components needed to be designed to support the equipment in the space while maintaining the flexibility goals of the infrastructure.

INTERIOR SHIP ENVIRONMENT (HVAC)

Two flexible HVAC designs, Under Floor Air Distribution (UFAD) and Overhead Air Distribution (OAD), are utilized to provide maximum flexibility for rearrangement over the life of the ship. Flexible HVAC infrastructure is installed to serve the mission spaces.

The UFAD uses a fan room with excess capacity, an under-floor supply plenum, an overhead return plenum, variable air volume (VAV) supply diffusers, a variable speed drive (VSD) motor controller, temperature sensors, a pressure sensor, connection boxes, and a ventilation control panel. The UFAD overhead return plenum uses slots along the perimeter of the space to capture equipment heat at the source. Ceiling panels used in creating this overhead plenum can also be fitted with ceiling return grilles as necessary to capture heat from above equipment located in the center of the space.

POWER AND LIGHTING

The majority of warfare system equipment loads, located within the mission spaces, utilizes 115V, 1 phase, 60-Hz power. Power panels located in spaces designated as “Flexible Infrastructure” will be equipped with female output connectors. No other panels or boxes will have connectors. Systems requiring a 115V, single-phase receptacle within a flexible infrastructure area will be fed with a flexible infrastructure receptacle. Receptacles located in areas without flexible infrastructure bulkhead track will be grounded using accepted procedures. The spaces designated to receive electrical flexible infrastructure are outfitted with power distribution equipment and associated feeder cables to support the allotted power.

Lighting and receptacle systems in the spaces receiving flexible infrastructure are intended to provide illumination levels and receptacle requirements per the ship specifications. The flexible lighting connection boxes are internal to the space. They can be bulkhead, overhead, or overhead track mounted; however, the preferred location is in the overhead above the ceiling plenum. These connection boxes allow for rapid reconfiguration of light fixtures through disconnection of connectorized cabling. The connector eliminates the need to tag out the lighting circuit. Lighting is then reconfigurable without tag out of electrical sources, and the necessary flexibility to rearrange spaces to suit changing mission requirements over the life of the ship is provided. General-purpose receptacles will be fed from a Ground Fault Circuit Interrupter panel containing a ground bus.

The flexible lighting design is a multi-component configuration consisting of the following:

- Distribution Fuse Boxes. Use of two distribution boxes located in the space will provide adequate power for lighting loads and allow for vital lighting interspersing for vital spaces.
- Modular Lighting Connection. Each box can accommodate four fixtures via its commonly keyed connectors. The boxes are configured such that they support the implementation. Fixture cable pigtails are connectorized to mate to the modular connection box. The baseline fixtures do not require modification or testing to accommodate the flexible infrastructure system.
- Switching Components. Switching devices will vary dependent upon the functionality and requirements of a given space. Switched distribution boxes are not used.

BELOW-DECK WIRE AND CABLEWAY DESIGNS

Standard hangers using studs, bolted standard tiers, or hangers connected to predrilled holes in the deck track provide a path for the transition of cables through flexible infrastructure spaces. Forward and aft wire and cableways are placed between every other track opening along the deck. Port and starboard wire and cableways are run above and perpendicular to the forward and aft wire and cableways between every other row of track. Wire and cableway volumes are sized and located such that they do not restrict airflow beneath the false floor.

UNIQUE SHIP DESIGN SPECIFICATIONS ADHERENCE ASSOCIATED WITH FLEXIBLE INFRASTRUCTURE

Shock Requirements

Deck track, bulkhead track, overhead track, portable stanchions, modular bulkhead track, and associated fittings meet shipboard environmental qualifications.

Bonding and Grounding

Currently, testing is being conducted on a vessel that has flexible infrastructure installation to determine if the direct current resistance and radio frequency impedance measurements meet the minimum values.

Security Concerns

The *Ford*-class aircraft carriers will carry a host of information systems. The principal subsystems of the future aircraft carrier with Information Assurance components include:

- Mission control systems

- Surveillance systems
- Navigation systems
- Communication systems
- Shipboard control systems
- Weapons control systems
- Network infrastructure

The approach to physical security for the class is based on requirements. The designation of the spaces assigned determines the ship infrastructure and design requirements for services, doors, hatches, bulkheads, locking devices, and monitoring systems. Space security requirements are established based upon the systems and functions being conducted within the space.

Sensitive Compartmentalized Information Facility (SCIF)

In the context of the new carrier flexible infrastructure design, only Permanent SCIFs are part of the flexible infrastructure design. For the purposes of this discussion, a Permanent SCIF is defined as an area aboard ship accredited for Sensitive Compartmented Information operations, processing, discussion, storage, or destruction over an indefinite, generally extended period. The term "Permanent" is an accreditation category, not a spatial reference. In the consideration for incorporation into the flexible infrastructure design, three options are being considered for Permanent SCIF applications that include fixed installations as are currently utilized on *Nimitz*-class aircraft carriers, flexible SCIF configurations within the requirements outlined above, and a combination of facility components of each. Current assessments being made are based upon deployment concepts of operations for the functions within SCIF spaces associated with aviation operations; a mix of these options may prove optimum. As the space design matures, considerations for physical and informational security are being included and special features are being incorporated into the flexible infrastructure design to account for the special needs of establishing a SCIF in the flexible infrastructure environment.

ENABLING PROCESSES FOR UTILIZATION OF FLEXIBLE INFRASTRUCTURE CONCEPTS

In the previous sections, the reasons for employing flexible infrastructure have been explored and the concept of the infrastructure design discussed, but successful implementation of flexible infrastructure also requires enabling processes to be established and discipline in their utilization to be adhered to through the construction and delivery of the ship for deployment. In the following paragraphs, some of these processes being developed and executed for flexible infrastructure utilization within the *Ford* class will be discussed. Integrated product team working groups have been formed to develop and carryout these processes with expected finite life spans as the processes mature and complete.

Space Identification

Once it is determined that utilizing a flexible infrastructure approach is desired and some design concepts and constraints are determined, it becomes necessary to assess and define where the approach will be applied. While at first pass it would seem that any space that utilizes electronic equipment should have the infrastructure installed, it becomes quickly apparent that this may not be the case. Physical constraints and space limitations within the ship design such as those associated with structural design and survivability; location of through services, such as piping, which passes through or encroaches upon spaces while not necessarily associated with the function of that space; equipment height; frequency of expected modernization of the equipment within a space; and acquisition costs associated with specific configurations all can influence where flexible infrastructure is utilized and which component aspects are employed. As a result, specific working groups have been chartered to assess and make recommendations on the application of flexible infrastructure.

In 2005, the Future Carriers Program Office established a series of working groups that supported establishing how flexible infrastructure would be utilized. They included participation by the program office, the government warfare systems engineering community, the shipbuilder, and the Commander, Naval Air Forces, which fostered collaboration and consensus across the span of stakeholders for this new ship class. The Space Category Definition Working Group was chartered to develop selection criteria; develop compartment recommendations; initiate general arrangement options; establish the footprint for the Decision Spaces; identify and allocate parametric limits for ship services; define the areas that required flexible infrastructure; and group the required functions maximizing flexibility, the ability to reconfigure a space, and workflow. The Design-Build Working Group was established and contributed to definition of design requirements and boundaries, identification of the optimum build sequence for the spaces considering the shipmaster build plan, and identification of through service systems that may effect utilization of flexible infrastructure components and the space configuration. The Command/Decision Centers Working Group was formed to optimize Command and Decision Centers in support of aircraft carrier missions and warfare mission areas and map functional information to Center display requirements to determine best use for reduced manning and flexibility.

In 2007, the Operational Design Working Group (ODWG) was established to mature the work of the previous working groups and focus support for ship construction. Its charter addresses key attributes to the application of flexible infrastructure in the ship design and furthers the products of the earlier working groups. These include arrangement concepts to provide guidance for design and determination of unique operational, physical, or functional compartment requirements, such as environmental aspects like noise and classification of spaces as previously discussed. The ODWG defines equipment locations based on internal space and/or watchstander functions to meet platform mission requirements, minimize negative impacts to ship key performance parameters and other requirements, and minimize impacts to ship design/construction, infrastructure, and cost.

Preplanned Product Improvement (P3I)

The ship construction contract includes a P3I clause to support installation during ship construction of designated developmental systems whose details were not known at the time of ship construction contract award. Managing the timely delivery of these government-furnished P3I systems and their associated government furnished information (GFI) to the shipyard greatly enhances the ability of the Navy to provide the warfighter with the latest capabilities available. P3I enables the late insertion of technology and, in combination with flexible infrastructure, enhances installation flexibility for evolving, maturing, and/or new systems. P3I also requires significant coordination between the warfare system developers/providers and the shipyard to enable the shipyard to maintain the ship's design and construction schedule. The P3I Working Group was established to track and manage the flow of government-furnished information to facilitate timely dissemination of needed P3I system information to the shipyard. This enables design and construction to continue efficiently without delay and disruption and ultimately supports the delivery of systems for installation as the construction schedule dictates, while also enabling the system providers to continue their system development efforts while the ship is under construction.

BACKFIT TO *NIMITZ*-CLASS AIRCRAFT CARRIERS

Although the focus of the flexible infrastructure work to date has been on its application to the new *Ford*-class aircraft carriers, efforts are underway to apply the approach to the *Nimitz* class.

CVN 77 Implementation

CVN 77 became operational in January 2010 and as part of the design, a small compartment was outfitted with some of the flexible infrastructure concepts being developed for the *Ford* class. A government installation team installed equipment, taking advantage of the bulkhead track components. The primary reason for the implementation on CVN 77 was to provide for risk mitigation as well as introduction to the Fleet for learning how to plan and utilize such spaces. This space will be configured as mission needs dictate.

RCOH Opportunities

When *Nimitz*-class aircraft carriers reach their midlife, they are scheduled for an extensive availability. During this availability, they undergo refueling and a major overhaul, which includes upgrades to the warfighting systems and provides time for modernization. The USS *Theodore Roosevelt* (CVN 71) is in the process of undergoing an RCOH presently, and included in the plans during this period is the installation of applicable flexible infrastructure components in a four frame space interior to the passageways. This space, utilized by embarking organizations, includes operator consoles and equipment racks, the implementation of which will provide operational experience with the flexible infrastructure and provide risk mitigation for the *Ford* class for full system applications.

Additionally, this space will have the ability to reconfigure for future configurations to accommodate the needs of technology growth and refresh. The USS *Abraham Lincoln* (CVN 72) is currently in the initial stages of planning for an upcoming RCOH. Determination of application to spaces is being driven as much by business case analysis as risk mitigation. Multiple spaces and bents are being assessed for applicability of flexible infrastructure. Backfit of these technologies requires consideration of removal and modification of existing ship structure. This is not a consideration for the business case analysis of a newly designed ship. However, utilization of flexible infrastructure components for *Nimitz*-class ships is being strongly considered as these ships are expected to serve for at least an additional two decades as capital ships of the Navy.

LESSONS LEARNED/FUTURE ENHANCEMENTS

As the Aircraft Carrier Program Offices and the Navy begin to implement flexible infrastructure capability into its ships, additional opportunities for cost-efficient standardization in support of flexibility and reconfigurable spaces are becoming apparent. While the application of flexible infrastructure greatly enhances the ability to modernize warfighting systems quickly and cost effectively, ships still have space envelope constraints and ship services limitations that additional standardization on the system development side could help address. If all ships could have common equipment and electronic cabinet/rack configurations standardized (two to three sizes), which a system provider could invoke on vendors during the acquisition proposal process, ship designers and builders, as well as system component providers, could ensure their applications can be modernized easily and efficiently without major physical infrastructure modifications, maintain survivability requirements, and simplify test facility infrastructure and procedures. Additionally, if power and cooling not-to-exceed envelopes could be established, ships could maintain longer service life of support systems without costly redesign. Scalable solutions, fixed number of alternative implementations, and family of parts principles all are opportunities for enhancing the flexible infrastructure utilization.

In addition to the standardization enhancements, a lesson learned from comparing the actual acquisition results to the initial business case analysis is that breakeven of cost during the acquisition phase is dependant on the density of “Moore’s law” type equipment within the spaces being considered. While many of the non-financial benefits of outfitting these spaces for the flexibility of reconfiguring these spaces into a more equipment-intensive functionality are still valid, new construction acquisition cost limitations make it necessary to judiciously identify the spaces in which the flexible infrastructure would likely be frequently taken advantage of during ship life so as to optimize which infrastructure components would be applied within the spaces.

CONCLUSION

Implementation of flexible infrastructure concepts in the next generation of aircraft carriers, the *Ford* class, is being accomplished utilizing sound business case analysis to enable an affordable Navy capability that will be in the U.S. Navy Fleet when our grandchildren are called upon to defend this nation. The flexibility and capability to respond quickly, effectively, and efficiently to changing world environments, technology, and mission needs are critical to the viability of our Navy; and flexible infrastructure is another tool in our toolbox to ensure we can succeed.

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