REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 074-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	26 February 2002	Symposium Paper 26-27 February 2002

4. TITLE AND SUBTITLE
Which Came First, The Aircraft or the Aircraft Carrier?
Challenges in Designing Aircraft Carriers for the Future

5. FUNDING NUMBERS

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

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8. PERFORMING ORGANIZATION REPORT NUMBER

N/A

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Naval Surface Warfare Center Dahlgren Division
17320 Dahlgren Road
Code N10
Dahlgren VA 22448-5100

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

N/A

11. SUPPLEMENTARY NOTES
Prepared for the Engineering the Total Ship (ETS) 2002 Symposium held in Gaithersburg, Md. at the National Institute of Standards & Technology and sponsored by the Naval Surface Warfare Center & the American Society of Naval Engineers

12a. DISTRIBUTION / AVAILABILITY STATEMENT	12b. DISTRIBUTION CODE
Distribution Statement A: Approved for public release: Distribution is unlimited	A

13. ABSTRACT *(Maximum 200 Words)*
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14. SUBJECT TERMS	15. NUMBER OF PAGES
Ship-Aircraft Interface, Ship's Requirements, Margins	14
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. Z39-18
298-102

20020326 228

Which Came First, the Aircraft or the Aircraft Carrier? Challenges in Designing Aircraft Carriers for the Future

A Historical Perspective of Aircraft Driven, Aircraft Carrier 'Requirements', And Their Influence on Ship Designs

Craig A. Smith and Richard W. Johnson

Abstract

The US Navy's Next Generation Aircraft Carrier Program (CVNX) is currently in the early phases of design and the first of the class is scheduled for delivery in 2013. Each ship of the design is expected to have a service life of over 50 years. Current requirements definition processes for the ship's aviation functions tie performance parameters to past, current and near future airframes yet the class will fly multiple generations of aircraft during its expected life span. Are there requirements definitions strategies that will enable less costly upgrade paths for the class than those currently implemented?

We examine, from a historical perspective, the traditional upgrade process that aircraft carriers have taken and propose alternative methods based on a different, "system of systems" perspective. Approaching design challenges from this larger viewpoint allows evaluating engineering trade space on both sides of the Ship-Aircraft Interface. The implementation of such new strategies, it is felt, can result in engineering benefits to each of the individual elements of the larger weapons systems **and** reduce the Life Cycle costs of that larger weapons system as a whole.

Introduction

In a paper in which the stated purpose is to define, in some detail, the issues and trade spaces encountered in designing a ship whose primary purpose is to operate and support aircraft, there are many obvious, physics defined, areas to explore. Clearly these hulls present the naval architect some unique challenges when they are tasked to support a very large flight deck, high above the waterline, propel it at 30+ knots and, "oh by the way", maintain maximum stability to enhance the safety of the flight operations. Those issues and trades have been explored and are largely understood. While these trades will continue to be revisited, in efforts to get more flight deck space, or go a few knots faster, or keep the deck level in a turn, because the laws of physics, as applied by naval architects, govern them, the carrier platform is not likely to change significantly. Instead, this paper will focus more narrowly on the challenges facing aircraft carrier designers and program managers that can be positively influenced. The trade space to be examined, from a historical perspective, is that of the "Ship-Aircraft Interface".

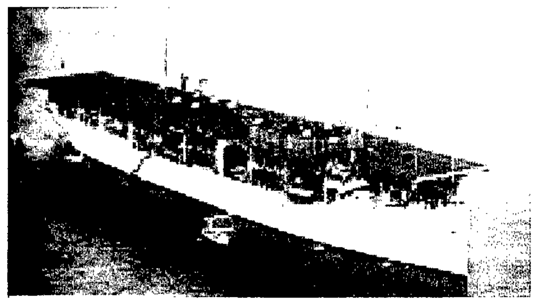
The short answer to the stated question "what are the issues in designing a ship to operate aircraft?" is the difficulty in designing ships to ***operate multiple generations*** of aircraft in a cost efficient manner. "Cost" in this instance has implications beyond dollars. The challenge is not only to set aside dollars but also to set aside space and weight for those future generations of aircraft. That process is by definition the creation of margins. The CVNX Operational Requirements Document (ORD) states in part, in a Key Performance Parameter, "Until significant ship configuration changes are made, CVNX class ships can not be expected to provide these allowances"[i] Significant effort is underway to regain the specified margins, with significant successes already realized. The question discussed here is, "Are there other perspectives and strategies that can enable additional margin recovery?". Or perhaps more significantly, "Are there strategies that will preserve and/or conserve these margins for the life of the class?".

CVNX has an advertised "service life" of 50 years. Consider that number for a moment: ***50*** years! For a historical perspective, the Wright brothers first flew in 1903. The first supersonic flight was in 1947, an "aviation span" of a mere *44* years. Consider also that the most recent class of aircraft carrier that had an operational life span of nearly 50 years, the MIDWAY Class, operated every operational Navy fighter from the F6-F Hellcat to the F/A-18C Hornet, not to mention the support aircraft that accompanied the power projection aircraft. While the skill and ingenuity of the aerospace engineering community is to be greatly admired, it is hard to imagine what the 2002 version of the F6 "Super Hellcat" would have looked like if they had been tasked to engineer 50 years of "series upgrades" to evolve that airframe into a supersonic fighter/attack aircraft capable of carrying the Navy's latest precision munitions and sophisticated electronic systems.

It is a tribute to the versatility of the aircraft carrier designers of the late 1940's that MIDWAY operated alongside SARATOGA, KENNEDY, and THEODORE ROOSEVELT (carriers of four distinct classes) in the Gulf War, performing the same missions, and with some exceptions, the same effectiveness. Let us examine the "process", the incremental upgrades that made this amazing (and ***very*** expensive) feat possible, and determine if there is a more efficient and ***less costly*** way to design a "50 year" aircraft carrier. How *did* we get into the habit of designing aircraft carriers "one aircraft at a time"? Is there a better way, and if so, can it be defined in such a way that it is achievable?

Historical Precedent

When the General Board of the Navy recommended to Congress in 1919 that the collier Jupiter be converted to the first aircraft carrier LANGLEY (CV 1), the first SHIPALT to upgrade a previously functional ship because of "new" aircraft



LANGLEY (CV 1)

requirements came to be. Cdr. Kenneth Whiting, the LANGLEY's Executive Officer, stated when the conversion of the Jupiter was finished, 14 months late, [on 20 March 1922] "We thought she could be converted cheaply. That was a mistake however." The Navy attributed the cost overruns and delay due to late changes in such areas as flight deck design and installation, decisions on having an island or not, and the design of the arresting gear.[ii] This was the first, and certainly not the last time it was discovered that modifying an existing platform to support the "latest" generation of aircraft was a hard task and would be expensive to accomplish. It should be noted that the "requirements", as defined at the time, were largely to determine how to take aircraft to sea at all, and, if these designers did not build in "growth margin" for the future, it was perhaps because there may not have been a future at all if they failed.

Since the commissioning of the USS LANGLEY (CV 1) all subsequent aircraft carriers have tried to reflect the needs of their primary weapons systems, the embarked Airwing. The challenge has always been on how best to achieve that goal in light of aircraft that evolved in months, and aircraft carriers that evolved in years. A January 1922 letter to the General Board from the Bureau of Naval Aeronautics recommended that USS LANGLEY CV 1 be fitted with new catapults to handle the newer, heavier, largely metal monoplanes that were being designed, vice the bi-planes she was originally modified to operate with. It stated "The preliminary mission of the carrier is to get planes in the air quickly, both torpedo and combat planes."[iii] LANGLEY's upgrade path was short however, as the lack of growth margin condemned her to be replaced in her role as a fleet carrier in 1936 by the new WASP (CV 7), and spend the early portion of WWII as a converted seaplane tender, relegated to aircraft transport duties, until she was lost in action in 1942.[iv] The rapid evolution of aircraft had outstripped her ability to support them.

Early carriers (pre WWII designs, CV's 2 through 8) shared with LANGLEY much of the experimental mind-set of LANGLEY's designers. There were no combat "lessons learned" yet, so the designs reflected everyone's "best guess" as to what a combat aircraft carrier "should" be. That is not to say that lessons were not learned through this experimentation process. The design spiral *did* progress.

RANGER (CV 4)

Requirements during this period, in addition to being aircraft driven, were also defined by the treaties of the day and each new ship in general reflected the lessons learned of the previous.

RANGER (CV 4) for example, in an attempt to operate the same number of aircraft as LEXINGTON (CV 2) and SARATOGA (CV 3) on less displacement, proved to be too small.[v]

CV 5, YORKTOWN, the first of a class of three, built as large as the Washington Naval Treaty would allow, was a much more satisfactory design. It is however noted that *none* of the pre-ESSEX carriers that survived the war survived the revolutionary advances that the aircraft that launched, and recovered aboard them, had made. All were either considered "light" carriers by the end of the war due to relatively small, pre-war treaty driven size or were considered "obsolete" or worn out by war's end and all were retired shortly thereafter. This was true in part because of added weight put on during several major re-fits during the war to not only make battle repairs and upgrade the prewar self-defense batteries, but also to keep pace with the rapidly evolving aircraft and concepts of aircraft operation resulting from combat experience.

The ESSEX (CV 9) and TICONDEROGA (CV 14) class proved to have enough margin or room for growth for continual upgrade as naval aircraft continued to progress. This room for growth resulted both from the abandonment of pre-war treaties and the vastly increased "survivability" features that were inserted due to WWII experiences and combat losses. Many of the ships that survived WWII intact and were not too badly worn went on to serve in the jet age in both Korea and Vietnam. These ships made 25 Korean War cruises[vi] and a staggering 48 Vietnam Combat deployments, including the last of the war by ORISKANY (CV 34) from 16 Sep 1975 to 3 Mar 1976.[vii] Keep in mind that the MIDWAY Class, FORRESTAL Class, KITTY HAWK Class and

ENTERPRISE were operating in the Vietnam theatre as well.

The post World War II era of aircraft carrier development prior to Viet Nam had seen dramatic design changes driven primarily by the advances in aircraft design. Some of the design changes during the Cold War era had been driven by the addition of strategic missions as well as the traditional tactical roles the carrier had always played. In 1957, the then-Chief of Naval Operations, Admiral Arleigh Burke best described the aircraft driven reasons for these changes in a speech in which he addressed the need for carrier modernization. "There has been a spectacular advance in aircraft design technology. The transition from propeller-driven aircraft to jet power has been fast. We are now undergoing another evolution from subsonic to supersonic speed at higher altitudes."[viii] The debate at the time was whether to replace the existing World War II aircraft carriers with a new class of "super carriers" or to do a major upgrade of the ESSEX class. The final decision was to do both. This was due in no small part to the demands that emerged during the Korean War taking jet aircraft to sea aboard the WWII aircraft carriers. In fact the angle deck and steam catapult first appeared in the "27 Charlie" conversions that were done on the ESSEX class carriers and the "One – Ten" conversions to the MIDWAY class.

MIDWAY after 110 Conversion added angle deck, steam catapults and Fresnel lens

They were only incorporated into the FORRESTAL Class design after their demonstrated successes aboard these other classes.[ix]

These conversions were massive and expensive as they involved the introduction of an angled deck, steam catapults, and relocation of aircraft elevators, in some cases from one side of the ship to the other. It wasn't long before the fact that the aging WWII aircraft carriers could only be modernized just so far became obvious. In justifying the FORRESTAL Class in 1957, CNO Arleigh Burke said, "The modernization programs have been the proving ground for the advances which have been made in carrier operating techniques. But the full combat effectiveness of these developments can be realized only in new construction".[x]

FORRESTAL (CV 59) as constructed

The transition of aircraft would continue at a fast pace for the next 20 years, with many different types, models and series of aircraft embarking aboard the various classes of carriers. Frequently the adoption of a new aircraft by naval aviation required the installation a specific ship alteration, more commonly referred to as a SHIPALT, to allow it to operate aboard the existing carrier fleet. Developments such as nuclear power, angled decks, advanced steam catapults, fresnel lenses, water cooled jet blast deflectors, and automatic carrier landing systems, with the required changes in ship board support systems, are but some of the more dramatic, aircraft-driven design changes that shaped the "super carrier" concept that culminated with the design and construction of NIMITZ (CVN 68) delivered to the navy in 1972. Clearly as we contemplate the design and features that should be incorporated into CVNX, we are dealing with a platform that has been "catching up" to the advances in aircraft since the platform was conceived. Each carrier class was designed for the aircraft of its day and modified (sometimes in very dramatic ways) for each succeeding aircraft that *couldn't quite* operate within the platform. Is this model the path to the aircraft carrier of the future?

The Challenge

The NIMITZ Class aircraft carrier has seen three generations of aircraft fly from her decks in the over 25 years they have been in service. NIMITZ will likely see at least two generations more before she is taken out of service. The requirements for each new NIMITZ Class ship as they were procured have largely stated, "support the current aircraft" while each new aircraft as they have been procured has dealt with many "requirements" that largely stated, "minimize change to the current ships". As a result little has changed in the basic aviation support functions provided aboard each ship. Each has essentially the same aircraft fueling system; the same aviation weapons magazines and throughput system, the same launch and recovery system, the same electrical servicing system, the same liquid oxygen servicing system and even the same tractors and tow bars for handling the aircraft, not to mention flight decks and elevators that appear very much like FORRESTAL. Most of the core aviation features of the class are much the same as when NIMITZ was commissioned in 1972. Admittedly, they have been overhauled, had their service life extended, some have even been replaced or upgraded, but their functionality and capacities remained essentially the same, attached to the legacy requirements set in the 1960's when NIMITZ was designed. to support the A-7A and F-111B. (Incidentally, the F-111 never flew off a carrier and the A-7A was in upgrade at design time.) Designing future ships to support current and in some cases obsolete and wrong aircraft and designing aircraft that can only operate off current ships is obviously not a formula that will result in significant operational advancement on either side of the equation. Previous discussion of the 27C alterations to ESSEX Class and 110 alterations to MIDWAY Class hopefully have made the case that it may in fact lead to the need for very costly modifications to the carriers in the future, hopefully not when impending or current war drive the urgent need for change, as was the case in the early 1950s as the Navy responded to the onset of the Jet Age and the Korean War simultaneously. Hopefully the case has been made that the survival of any class of carrier has largely depended on the "growth room" left to accommodate future aircraft after the design has been finalized and built.

Answering "The Challenge"

The Naval Aviation engineering community is currently contemplating what systems, features, and characteristics should comprise CVNX, the next generation of aircraft carrier, the first ship is expected to serve for 50 years or through 2063 from delivery in 2013. It is contended here that any successful design will, for the reasons stated above, "build in" as many features as is fiscally possible, to support aircraft of the future. Additionally, given that some features of the aircraft of the future remain unknown, it should have design features that acknowledge future change as inevitable and "enable" that change. Maybe this has been done by requiring design margins in the past but the trend has been for margin to be expended over time by adding new systems without removing obsolete systems.

This explicitly means that the design should ***not*** be based on specific current aircraft, or even specific near future aircraft. What follows are specific limited examples to support that contention and some recommendations on how to develop new design strategies to answer the challenges of Ship-Aircraft Interface.

Aircraft Carrier Bow after Final Recovery, Doing Aircraft Maintenance

As the subtitle of the paper suggests, this paper would eventually turn to "requirements" and their role in defining the ship and "Ship-Aircraft Interface". In the past, from 1922 on, "Ship-Aircraft Interface" related ***ship's*** requirements have been based on the characteristics of very specific "design reference aircraft" that have tended to be existing airframes or airframes in very mature acquisition programs, presumably because of a desire to design to "hard" numbers.

CVNX, like NIMITZ, will operate 4 or 5 generations of naval aircraft in its 50 year lifespan. Life cycle cost (LCC) reduction is a stated goal of the CVNX program. A historical perspective suggests that tying aircraft interface designs to current and near term aircraft characteristics is likely to build into the ship the requirement for costly alterations in the future, as the characteristics of future aircraft push the envelope established by current designs. This in turn will likely be a system LCC driver unless rectified. Conversely, a second consequence of short horizons in the requirements definition process is to limit the aircraft designer to the capabilities of the current ships. Much of the ***point*** of acquiring new aircraft is to enlarge the performance envelope of the CVN/Aircraft total weapons system. To state the obvious, and the assumed subject of the companion paper to this, the designs of carrier aircraft ***are*** affected by their being carrier-based. To whatever extent is possible, the carrier element of that larger weapons system should ***enable*** carrier aircraft rather than limit them. As the aircraft are a major element of the ship self defense system, more "combat capable" aircraft are a "good thing" for the ship as well. NO Navy pilot who has ever flown in combat has <u>not</u> wished for "a little more gas" or "a few more weapons" or "a little more thrust to weight" at some point in his career. We can examine some more recent history and examine the "lessons learned" that can be derived and suggest a design strategy superior to "ship design, one aircraft at a time".

The consequences of "short-sighted" requirements definition

Consider the following specific example. The last upgrade to the jet blast deflectors (JBDs), which was incorporated on two of four catapults in NIMITZ new construction, was the Mark 7. The Mk 7 design in part added cooling panel modules, which were removable and also lengthened the panels so that they stood higher above the deck when raised. The F-14A in afterburner or Combat Rated Thrust (CRT) was one of the design drivers.

F-14 in After Burner

The new modules did improve heat dissipation to a level that was acceptable for the F-14A in CRT and the additional height provided was necessary due to the fact that the F-14 kneeled (lowered the nose) on the catapult to achieve take off attitude rather than using the nose strut extension (nose raising) that the F-4 had used previously. The F-14 tended to put heat over the JBD unlike the F-4 which had tended to put heat short of the JBD. (It is also interesting to note that the introduction of the F-4 to the fleet generated a SHIPALT which installed flight deck cooling short of the JBD due to the lowered exhaust pattern with the nose strut extended.) The next series F-14, the A+, with the upgraded F100 engines, was found to be too hot for the most recent JBD redesign and it was restricted from afterburner catapult operations. The point here is that the next series of the design reference aircraft had operations limited by lack of margin in an installed ship's system. The option of CRT catapult shots, as limited by other design factors, will always allow higher gross weight catapult launches and therefore larger/heavier payloads may be considered.

The next consideration of JBD redesign occurred in 2000-2001 during the CVN-77 program when passive (non-water cooled) JBDs were briefly explored for inclusion as a ship's feature. When the heat dissipation requirement was defined it was decided that the requirement would be based on the F-14A not the A+ (or the F-14 B & D which were by now operational). This was because the A model aircraft was certified for after burner catapult launches, the A+, B and D were not certified and therefore could not serve as the design driver. The JBDs remained unchanged; the current design met the current requirement and, at the time, there were no other compelling reasons to adopt passive cooling techniques.

Ship requirements should be "untied" from specific aircraft and/or specific aircraft characteristics

As the CVNX acquisition program makes the transition from detailed ship's specifications as a design reference, to an Operations Requirements Document (ORD), ship-aircraft interface systems that are candidates for re-design should adopt an "ORD-like" format.[xi] Systems should be defined in terms of function, "threshold" and "objective" performance parameters. Clearly the short reach "threshold" values should reflect minimum values needed to operate the current and near future aircraft (the status quo). This will ensure that the design can be superior to that which would be produced by current methods. Establishing the "objective" numbers should involve the participation of the major systems commands; the aircraft prime contractors and their principal vendors in the design process. Clearly there are trends that have been established in the aviation industry and they have some idea of where they want more design trade space. Requirements should be based on the question,"How much could you use if I could give it to you?" not "How much do you need in the short term to operate?" Designers should be asked to consider a "reach" solution rather than be limited to the minimum to operate today. A means to ***reward*** design success relative to stated values should be instituted with development cost, as an independent variable, as an important factor. Reward those who achieve the objective under budget rather than ***award*** the total budget for minimum achievement.

"Stove Pipe Engineering" The consequences of "Layering" new requirements on old without a systems engineering perspective and approach,

A more recent aircraft interface issue has arisen with the latest generation of aircraft and aircraft expendable countermeasures. Currently deployed and recent aircraft were equipped with limited countermeasures and decoys that were "ejected" to divert enemy munitions deployed against the aircraft. There has been considerable effort, expenditure and development in aircraft defensive systems over the last several years and numerous new and immensely more capable systems are being introduced for fleet service. In many ways this is the introduction of a new capability and new class of store to the already "full" weapons system. Generally categorized as airborne expendable countermeasures, the introduction of these systems and stores to the aircraft carrier has presented a considerable design challenge. This challenge has resulted from countermeasures going from a small ejectable IR and chaff type units to a forward or aft firing "missile" type store with all the requisite weapons "type" storage requirements. Specifically the F-18 E/F will carry a wide array of countermeasures resulting in a 30% increase of stowage requirements onboard current and future carriers. Ready service stowage requirements will increase 6 fold to support the future Airwing. The ready service stowage must be in a secure area within a magazine, incorporating all the currently required physical alarm and fire protection systems. Along with this are many other considerations that must be evaluated such as accessibility to the flight deck, preparation areas, personnel safety, survivability and space arrangement/rearrangement to meet this "near term" requirement. The current effort to integrate these stores into CVN 77 has resulted in an engineering change that is the likely standard for the rest of the existing CVN 68 Class ships. The current design displaces (2) squadron work centers, (1) ordnance work center (1) line shack, and the only currently available flare handling/banding space in the class. This particular space had, by the way, been created in an earlier SHIPALT, which had converted an aircraft Cartridge Actuating Device (CAD) ready issue and stowage area. That ALT had been driven by an emerging (at the time) demand for increased aircraft CAD stowage and issue capacity, which was not a "requirement" in the original NIMITZ design. This is a classic case where new requirements have displaced old requirements, which are still valid, but no longer represented by funding. Encroachment has become the name of the game. There is still the requirement to band and stow aircraft flares and issue/stockpile ready service CADs in support of Airwing operations. The functions of the other displaced spaces are no less valid. Unfortunately the removal and re-insertion of valid functions by expansive (and expensive) SHIPALTs is not uncommon.

Introduction of "new" functions without a 'system of systems' perspective, and integration effort, is a LCC driver that is not justifiable in future systems

Expanding the capability of the CVN platform to support her embarked Airwing aircraft by adding new capabilities and additionally creating additional trade space for the aircraft designers is an important ambition. The examples presented thus far have illustrated the current layering of additional capability on top of existing systems. This continues on a platform that has diminishing margin for growth. The addition of "new" capability one aircraft at a time has evolved to the point that it is a "zero sum game", which displaces current spaces and functions to gain others, as illustrated above. We began some time ago to "rob Peter to pay Paul". If each new addition displaces/replaces some current function, are there current functions and systems that are logical candidates for removal that a true "systems engineering" approach could identify? Are there systems that are more logical to down scale or remove than the functions that have been displaced in the last round of aircraft driven SHIPALTS?

Opportunities lost by "tying" requirements to "historical" aircraft

As hard as it is to modify requirements to "add" major new capabilities to the aircraft carrier, it has proven to be even harder to delete systems that have been overtaken by advances in modern aircraft's systems technology. When the NIMITZ was designed, the embarked Airwing of 80+ aircraft ***all*** used liquid oxygen (LOX) systems for the pilots. Each NIMITZ Class aircraft carrier is delivered with two high pressure, cryogenic liquid oxygen and nitrogen generating plants. Either plant alone, for redundancy and survivability reasons, is capable of servicing the 1972 Airwing of 80 LOX consuming aircraft. These plants were a logical choice at design time as they were one of the few choices available that met the volume and purity requirements demanded of the 1972 Airwing. Since NIMITZ was designed a number of aircraft have been introduced with Onboard Oxygen Generating Systems or OBOGS, and they no longer require liquid oxygen servicing at all. All F/A-18 models, the C/Ds as well as the E/Fs do not need liquid oxygen. All future aircraft are required by congressional law to have some sort of self-contained regeneration breathing system. The E-2 Hawkeye will be the only component of the projected Airwing of 2015 that is forecast to require liquid oxygen, totaling only 6 aircraft. The system in that aircraft is for emergency use (in case of aircraft depressurization). Per aircraft sortie in the Hawkeye, there has been a very low oxygen consumption rate compared to the current/past tactical aircraft that used LOX systems.

Liquid oxygen is a very dangerous substance, and extensive training is provided to the personnel who service the aircraft and maintain the system that produces this explosive material. Additionally, the costs of maintaining and periodically replacing the two plants per carrier are considerable. Each unit has an acquisition cost of over 3 million dollars and a considerable documented history of high maintenance and overhaul costs. Money is not the only adverse cost of this system. With the problems of weight and CG that the NIMITZ Class carrier is experiencing, the cost of maintaining these plants can also be measured in terms of excess weight and adverse effects on center of gravity, as these plants are installed on heavy concrete foundations. Due to their two story sizes and location, directly off the hangar bay, they occupy considerable space and their removal would provide space for recently displaced aircraft maintenance functions or space for emerging requirements.

Recent discussions that have considered their removal have shown the presence of these large, expensive units has a considerable amount of inertia and proponents largely quote the "requirements". The nitrogen and limited oxygen that will be consumed from these plants is "consumed" in gaseous form. Thus the designer and systems engineer must ask if a downscaled and far less expensive gaseous capability can be substituted for these plants. One concern centered on the purity delivered by a liquid plant, which is 99.5% vice that of a gaseous plant of 94%. That requirement was relaxed to the 94% standard in January of 2001.[xii] Should the aircraft carrier continue to have twice the capacity required to service 80 aircraft with liquid oxygen when there will be only 6 aircraft on board that require it? Is it more cost efficient from the larger systems perspective to add OBOGS to those 6 aircraft or modify them at least to use gaseous systems than to procure and maintain a LOX plant for 50 years? It thus becomes very clear that a hard linkage into the NAVAIR community is essential to making such a proposed ship system change.

Another function aboard the carrier that may be a logical candidate for downscaling and/or removal, again due to the advances in aviation, is the Jet Engine Test function and associated facilities. The jet engine test cell is a very large facility adjacent to the hangar bay that could provide much needed space to other aviation functions. Again, it is in the ships specification, but why is it there and is that reasoning still valid? When NIMITZ was specified, the common procedures and logistic support system for jet engines resulted in engines "cores" being delivered as separate units from their "accessories" such as hydraulic pumps and generators. Additionally some engines were so large that they came in pieces that had to be assembled aboard ship prior to installation in the aircraft. The F-14 core engine and afterburner section with associated engine nozzles is a prime example in this category. The jet engine shop and associated test cell certainly were required when engines needed to be assembled and numerous fittings made up outside the aircraft prior to installation. In 1972, jet engine changes took days and it made perfect sense to check the integrity of all the fittings and assembly that had been accomplished prior to aircraft installation. Errors in assembly, if found after installation, would have caused considerable additional work and delay. The current trend, again starting with the F/A-18, is for engines to be shipped pre-assembled Ready for Installation (RFI) and checked by the manufacturer or rework facility using scrupulous quality assurance programs and shore based test runs prior to issue to the supply system. F/A-18 engine changes take hours and few new engines are found to be defective when tested in the aircraft (as all engine changes are required to be tested in the aircraft, even if they went through the test cell).

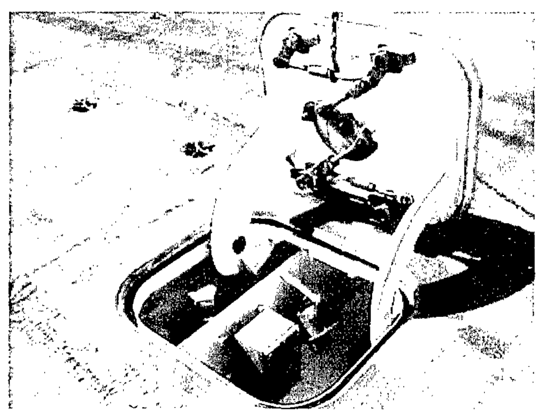
It is noted that the F/A-18 engine can be and is repaired aboard ship by changing engine modules (it comes in several that can be ordered through the supply system) but it ***could*** be supported by a "replace only" program rather than continuing to support the repair or replace system. Again the question is, which makes more sense from a systems engineering perspective of the larger ship/aircraft weapons system? An F/A-18 engine currently can be tested 3 times before flight. It is tested once at the rework site, can be tested once in the test cell and once in the aircraft before scheduling it for flight. Has technology advanced to the point that perhaps one of those tests can be eliminated? The jet engine test cell has a number of associated sub-systems for fuel, firefighting and remote operation of the engines that are considerable cost drivers. This consideration is not for the elimination of testing, but to move that function ashore where it is considerably easier and less costly and to free the space and budgets (dollar and weight) for additional capability aboard the CV.

Requirements de-coupled from historical aircraft may regain needed design margin and enable greater success of larger systems engineering practices

The argument has been made to design ship aircraft interface systems with future generations of aircraft in mind. Further it has been debated that the continued layering of new features on top of existing systems has consumed much of what is left of the aircraft carrier's growth margins. It has been suggested that a systems engineering approach should be adopted that considers the ship and aircraft as a total system. Implicit in that suggestion is the concept that the engineering design trade space includes opportunities for upgrade/change on both sides of that interface and the best engineering solution and affordable answer may well involve both. When considering trades across the interface, all current and future aircraft should be considered.

System integration is far easier (and less costly) if it is accomplished in the design phase, on paper or in ones and zeros, rather than in steel after delivery

An example of an aircraft interface system where use has evolved considerably since NIMITZ design is the Aircraft Electrical Servicing System (AESS) stations. This system first appeared aboard the carrier when the weight and poor safety record of the installed battery systems in aircraft suggested their removal and an external electrical support for engine start and routine maintenance be installed in the ship. Over the years aircraft have developed numerous sophisticated computerized and electronics systems dedicated to the weapons system, navigation, countermeasures (ECM), counter countermeasures (ECCM) and other sophisticated electronic devices. Many of these systems, as the power of transmitters and sensitivity of receivers increased, became increasingly more dependant on high quality power for setup, repair and troubleshooting. During the same time span aircraft began to be introduced with Auxiliary Power Units (APUs) and no longer required ships electrical power or air to start. In general the primary use of this system has gradually shifted from aircraft start to aircraft maintenance.



AESS Combat Hatch

The system designed and provided with NIMITZ is a 115V, 3 phase alternating current system and is based on transformer rectifier technology. Several current generation aircraft (EA-6B, E-2C and the F/A-18) have had difficulty in using the current transformer rectifier technology based system, whether it be due to the fact that the aircraft loads exceed the current systems capacity (as with the E-2C) or it be due to the fact that they are very sensitive to power cleanliness and/or minor voltage disparities. Some aircraft appear to only accept power from a small percentage of a ship's 60+ AESS stations due to their low individual tolerances for electrical system noise/voltage error. As a result, this system has generated several proposals for upgrade due to the increasing importance of system issues that have emerged as aircraft depended more on this particular ship's system.

The E-2 2000 program has sponsored one design effort to upgrade the system to an anticipated 90KVA peak load that will come with that aircraft. The E-2 additionally requires a technology that will tolerate the fluctuations in the 90KVA load that result from the air conditioning system in the aircraft going on and off surge. The current system is prohibited from use to support the aircraft environmental control system (air conditioning) because it cannot tolerate the load fluctuations this system causes. Current efforts are considering upgrading only a sub set of the ship's stations to support this one aircraft type, due to cost and design issues that revolve around the size and weight of a 90KVA cable. Perhaps this will result in diminished flexibility of the flight deck in supporting all Airwing aircraft.

The shipbuilder has several separate initiatives currently underway to deal with power quality (electrical noise issues inherent to transformer rectifiers) and voltage control. Both rely on solid-state electronics and have the capability to provide high quality power of any type. They can be easily designed with positive feedback to further adjust power quality to the aircraft's standards if an interface and communication standard can be/are specified.

As an additional consideration, there has been a trend in aviation over the last several designs to remove distributed hydraulic systems that drive flight controls from the aircraft. Future Aircraft will rely on high DC voltage electro-hydraulic actuators at the control surfaces. The actuators being developed in the aircraft industry are currently 270V DC. This is introducing a 270V DC bus/distribution system into the airframes and will introduce the need for 270V DC to troubleshoot, repair and test those systems on the bus. The "requirement" for 270V DC has yet to appear on paper as an aircraft carrier "requirement" but will be a requirement to meet shipboard needs of future aircraft. It is better to address those requirements early than making expensive "fixes" after the aircraft is introduced to the fleet.

There are several possible solutions to providing 270 Volt power to the aircraft. The first option is for the aircraft to build in the electronics to convert 400HZ AC power on board the aircraft from current or improved systems aboard the carrier. This solution adds the cost and weight of the conversion equipment to every aircraft. It also penalizes the combat power of the total weapons system by requiring the aircraft to haul that weight on every mission that the aircraft will fly at the expense of additional fuel or ordnance. Another option is to add another unique piece of portable support equipment to the flight deck/hangar deck to convert ship's power into an acceptable form for the aircraft. This is the solution the current E-2C uses with several small motor generators that are required to convert shipboard 440V power into acceptable 400HZ power for its systems. In contrast, the EA-6B community prefers power from the NC-2, a self-propelled power cart. The combat power of the total ship-aircraft system is penalized in these cases by the cost and volume these ancillary systems consume that cannot be dedicated to the acquisition and storage of aircraft and weapons. A third choice is for improved electronics based power supply systems in the ship designed to provide either type of power, on demand, as dictated by the aircraft, through a single cable.

It would appear an opportunity exists to merge these several disparate design efforts into a forward thinking solution that will support the current 400HZ aircraft and aircraft of the future with 270V DC from the same electronics, at the same station, through the same cable. With today's highly computerized aircraft, it is possible that initialization and control of the power may be accomplished from the aircraft side of the interface, if communication paths are provided and interfaces defined. In principle, the aircraft requests a specific type and amount of power that is only "switched on" when that hand-shake is made and the request is understood. It may be possible that 270V DC control system aircraft of the future would still prefer 400HZ for electronics and they may be able to use both simultaneously.

This issue provides a unique opportunity to demonstrate systems engineering based integration of ship aircraft interface systems that are designed for the future

That effort, to provide a flexible power supply, should involve NAVSEA, NAVAIR, the aircraft electrical system designers and the designers of the next generation solid state AESS systems. It should be funded and managed at a system level rather than as a piece part of an individual ship or aircraft acquisition program. If we don't take a whole ship/aircraft view we will continue to produce individualized support equipment, "one aircraft at a time".

Ship alteration "one aircraft at a time" is a byproduct of lack of interface standards

If we are going to stop growing the carrier one aircraft type at a time, it seems logical that we need to decouple interface design and therefore funding from individual platforms and programs. The problem is that there is not a funded technical code that is empowered to speak for the present and future carrier aircraft in the plural form of the word. In the above system; where does the ship design community go to make the proposal that the E-2 and JSF use the same cable to receive two kinds of power? If there is a cost driven logical trade that emerges, which suggests one of the two platforms should introduce a new design parameter (different AESS cable receptacle for example) what authority exists to ensure the most cost effective solution is reached from the total weapons systems perspective? There should immediately be an AESS interface standard that is known and understood by both the ship builder and the aircraft industry that defines in great detail both the 400HZ and 270 V DC systems. Currently there is not. At the heart of the above recommendation is the creation of that standard immediately. While the need is real, the authority and funding are not.

The buzz word for the idealized interface that is popular today is "Plug and Play". It describes the concept that when one airframe leaves, the next fits in perfectly without additional ship alteration requirements. Achievement of this idealized goal would do much to eliminate the need to design ships "one aircraft at a time".

It should be noted that the computer metaphor never suggested that the standardization that enables the consumer to remove and add cards to a home PC came without considerable work and years of collaboration among the competing hardware manufacturers. The PC card slots and underlying buses and communication codes were highly standardized after considerable design work to achieve the "ease" of the highly touted "Plug and Play" metaphor.

To achieve "Plug and Play" at the ship-aircraft level will require the same level of effort. Requirements will have to be future based and leave margin to be claimed by generations of aircraft not yet on the drawing board. An authority will have to be designated that can manage the trade-offs that will have to be made on the aviation side of the ship-aircraft interface. This authority should designate when a current function or functional capacity is now in excess of current need and be able to trade it for future needs.

This authority will have to "speak" aircraft (plural) and will do much to define the carrier of the future. The interface will have to move beyond technical design of hardware-to-hardware interfaces and also embrace functional descriptions and embedded processes. This authority should be able to define for the shipbuilder "reserved" volume that must be dedicated to aviation support activities and eliminate much of the encroachment issue that continually reappears at each Operational Advisory Group and after each SHIPALT. He should specify power consumption, cooling needed and all the support services his aircraft will require of the ship. Most importantly, this office must then manage the future aircraft to design and fit into that footprint. Failure to break the integration of aircraft "one at a time" paradigm can only result in the total weapons system being grown "one SHIPALT at a time".

Conclusion

We of the naval aviation engineering community have recently been ***specifically*** tasked to begin to build and transform the "Navy after Next". CVNX with its attendant 50 year service life is the most likely centerpiece of that Navy. We need to adopt new requirements definition and ship-aircraft acquisition strategies to enable us to meet that challenge. Failure to do so may result in the centerpiece of the "Navy after Next" having been designed to operate the aircraft of the "Navy before This".

It has been suggested that systems at the ship-aircraft interface should be funded and acquired at the system level and all stakeholders be invited to the design table. The systems at the interface should enable the extension of the aircraft design trade space wherever possible. We have also suggested that "short term requirements" should be abandoned when fiscally possible. When this results in a "one off" system for the first ship the cost of supporting the unique system must be weighed and evaluated versus the benefits realized.

There is at least one shining example of where this strategy is being utilized today. The current EMALS acquisition strategy demonstrates all of the above attributes. As a NAVAIR funded program many of the benefits of the new system will be realized on the aircraft side of the interface. There are real and measurable benefits to the ship as well. On the aircraft side, clearly the benefits are not "requirements" for current or near term airframes. Those airframes will all operate from steam catapults as well. The benefit realized is a clear attempt to expand the envelope available to the airframe design teams of the future. It will enable lighter and smaller structures due to reduced loads on the aircraft. Ability to control end speed in the low aircraft weight spectrum may also enable UAV/UCAV compatibility some time in the future. When EMALS is first introduced aboard CVNX it will indeed be a one of a kind system. Yet the trade was made to pursue it to realize the operational capability it will introduce.

This was and is, in our opinion, exactly the right approach to engineering the aircraft support function into the ship. We propose to evaluate the rest of the ship-aircraft interface systems in the same manner, and where possible, apply the same reasoning and same systems engineering approach. We propose following the EMALS example, starting with the AESS system.

Acknowledgements

This paper was commissioned by Mr. Al Kraft of NAVAIR who has represented aircraft requirements to the shipbuilding community for many years. What understanding we have of the programmatics and underlying issues we owe to Al. It goes without saying that there have been too many Captains, Air Bosses, Chiefs and flight deck personnel to name that have taught us the "trade" of flight deck operations. To those many folks that we have had the pleasure to serve with over the years, thanks.

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