

IMPACT OF AVIATION SYSTEMS ON AIRCRAFT CARRIER DESIGN

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INTRODUCTION

THE DESIGN OF AN AIRCRAFT CARRIER, perforce, is the greatest challenge in combatant ship design. Not only does it include all of the functional systems required in conventional combatants, but it must also address all of the aircraft related systems which are being discussed at this first technical symposium dedicated to design and maintenance of the aircraft carrier. The modern attack aircraft carrier and its embarked Air Wing represent a carefully integrated and highly complicated combat system. The interrelationships between the ship systems and the aircraft and aircraft oriented systems are numerous and often subtle. Therefore, it is important for those who

desire operational capabilities in an aircraft carrier to understand the aviation system design impacts. Many times, the less obvious interdependencies and interrelationships can be overlooked. This paper addresses the overall design criteria which affect aircraft carrier sizing and discusses selected aviation system functions which have considerable impact on the ship design process.

AIRCRAFT CARRIER MISSIONS AND FUNCTIONS

In terms of broad capabilities, the aircraft carrier must be able to accomplish the functions listed in TABLE 1.

TABLE 1

AIRCRAFT CARRIER CAPABILITIES

- Operate, maintain, and support naval carrier aircraft.
- Accept new aircraft types and concepts.
- Provide essential Command and Control facilities for Commander.
- Have speed and endurance to operate in assigned areas.
- Have speed and facilities to launch and recover combat-equipped aircraft.
- Provide simultaneous aircraft launch and recovery capability.
- Provide combat alert intercept launch capability.
- Permit long-term cyclic operations by embarked Air Wing.
- Permit acceptable combat air operations with degraded propulsion plant operational modes.
- Provide adequate level of overall aviation combat support: servicing, fueling, arming, maintenance, Air Wing facilities.
- Provide control of aircraft: on deck and airborne.
- Possess mission capable communications, intelligence, sensors.
- Provide adequate air/surface/subsurface defense systems.
- Possess strength, integrity, and redundancy to withstand damage from enemy actions.

The most significant difference between the aircraft carrier and other combatant type ships is in the ability to change rapidly the primary combatant system, the Air Wing. This quick change capability impacts on shipboard related aircraft functions and thus, impacts the overall design. As can be seen from Figure 1, a change in aircraft type can affect several ship/aircraft related func-

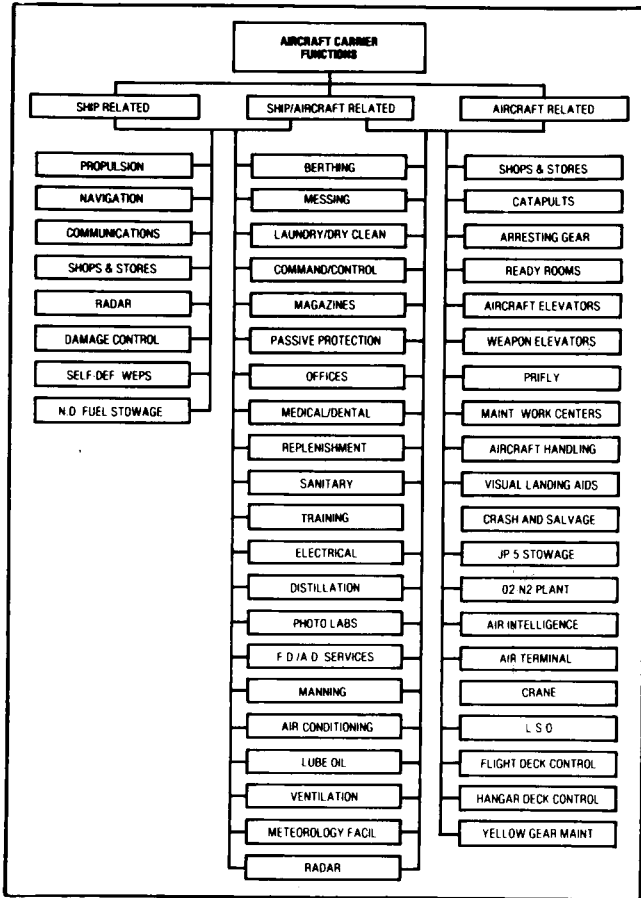


Figure 1. Ship/Aircraft Subsystem Relationships.

tions. Only a few ship related systems remain unaffected.

If maximum compatibility is to be achieved between the aircraft mix and the ship platform over the ship's 30 year life-cycle, there are several primary areas of ship design which must be related to specific aircraft system readiness functions. These functions include, but are not limited to, those shown in TABLE 2.

TABLE 2
PRIMARY AREAS OF SHIP DESIGN AFFECTED BY AIR SYSTEM FUNCTIONS

- Size of aviation maintenance, supply, weapon, and aviation support facilities.
- General arrangement of ship spaces.
- Types and sizes of material handling systems for engines, components, and weapons.
- Number and capacity of launch and recovery systems.
- Size of interior communications systems.
- Size and complexity of the operational and intelligence information system.
- Size and function of aircraft support shops.

The goal of the ship designer is to produce an aircraft carrier with maximum performance at

minimum life-cycle cost. However, as the demand for more performance increases, there is nearly always a requirement for an increase in ship size. TABLE 3 lists typical aircraft carrier performance features. The key to a successful design is in obtaining additional performance per ton of ship; not in increasing size and tonnage to obtain the desired performance features.

TABLE 3
TYPICAL AIRCRAFT CARRIER PERFORMANCE FEATURES

COMBAT CAPABILITY:	AAW, ASW, SUW, C&C
MOBILITY:	Speed, Endurance, Maneuverability
SURVIVABILITY:	Shock, Seakeeping, Damage Control
MAINTAINABILITY:	Ship Facilities, On Board Spares
HABITABILITY:	Living and Working Conditions
FUTURE CAPABILITY:	Modernization, Conversion

If the designer cannot improve performance without increased displacement, the problem becomes iterative. For example, if ship size increases, ship speed decreases unless shaft horsepower is increased or payload is decreased such that wetted surface is maintained relatively constant. Thus, a question arises as to how much speed, payload, personnel, et cetera, are required to accomplish the established mission. The key parameter in the design of an aircraft carrier is the establishment of mission capability requirements to meet projected threats.

MISSION IMPACT ON MAJOR DESIGN PARAMETERS

The mission and its associated operational scenario is the starting point in an aircraft carrier design. The mission establishes, through the operational scenario: 1) the number and type of aircraft to be carried, 2) the sortie rate, and 3) the desired ship endurance. These three parameters are extremely important since they drive the major ship sizing relationships.

Aircraft Mix and Carrier Sizing

The number and type of aircraft are instrumental in sizing the aircraft carrier. The type aircraft impacts flight deck length, hangar deck area, number of personnel to be carried aboard as part of the air wing, and the requirements for aviation support, operational, and control spaces.

In addition, there is a major interrelationship between the number and type of aircraft and the number of Air Wing personnel and their impact on

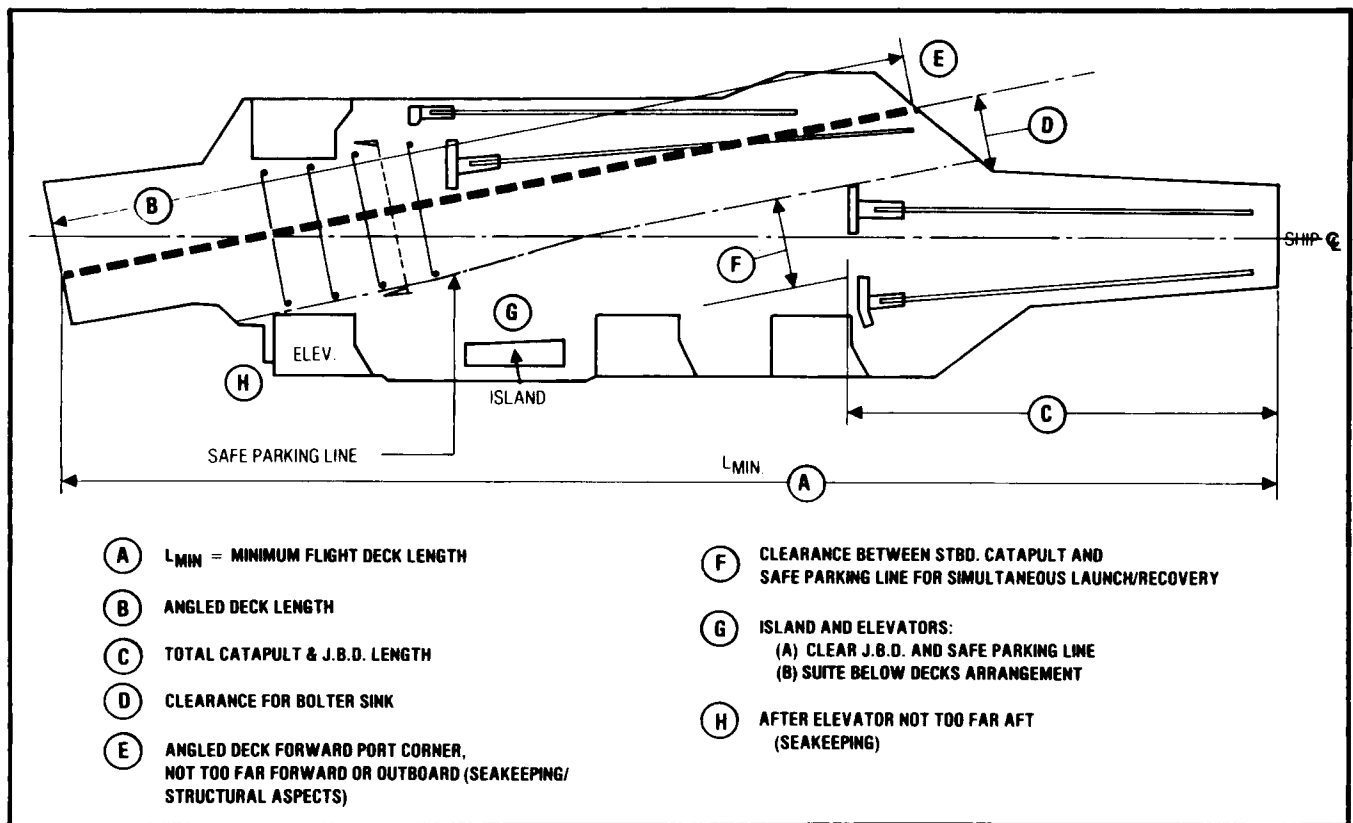


Figure 2. Factors Affecting Angled Flight Deck Size.

ship area and volume requirements for berthing, laundry and dry cleaning, messing, galley, scullery, stores, provisions, potable water, ships boats and rafts, head facilities, barber services, air conditioning, and other shipboard services. Since much of the NAVY's early stage design criteria is based on so many (X) square feet per man, manning becomes a critical parameter for space, weight, and volume calculations.

FLIGHT DECK LENGTH — The minimum flight deck length is driven by the major factors shown in Figure 2. In addition, the number of aircraft to be carried influences the size of both the flight deck and hangar deck area because safe parking area must be provided in the ship to satisfy the required aircraft loadout and still permit launch and recovery of aircraft. The type aircraft will influence angled deck length, elevator size, bolter sink clearance, catapult and jet blast deflector length, and required safe parking area.

In addition, the flight deck must also be designed to withstand the impact of aircraft landing, the wheel loads during catapulting, and the loads of parked aircraft; including the dynamic loading which occurs during storm conditions. The stresses due to aircraft imposed loadings depend

not only on the aircraft launching and landing speeds and weight, but on such factors as tire size, tire pressure, landing gear spacing, and location of center of gravity of the aircraft. Finally, the flight deck also forms the upper flange of the box hull girder.

ANGLED DECK LENGTH — The angled flight deck, in addition to improving flight safety, provides the advantage of permitting simultaneous launch and recovery of aircraft. Hence, the deck angle is selected to ensure that the landing area will be clear of the Jet Blast Deflector (JBD) for the port forward catapult and, in order to reduce air turbulence, the port waist catapult is usually moved inboard as far as possible. The angled deck must provide sufficient length for recovery of aircraft and also for launch of aircraft using waist catapults. The length required for aircraft recovery is a function of the:

- Ramp to first arresting gear wire (crossdeck pendant) including visual landing system location as related to touchdown point.
- Number of arresting wires, distance between wires and barricade gears. Wire spacing is in turn a function of aircraft controllability, ship pitch and roll motion, arresting hook characteristics, and wave off characteristics.

- Runout distance from last pendant.
- Turnaround distance to clear the aircraft from the recovery area after maximum runout from last pendant.
- Other requirements such as landing area angle (simultaneous launch and recovery), glide slope angle, hook to ramp clearance, and off-center allowance on aircraft runout.

The angled deck landing lane width is normally fixed at about 120 feet. The beam requirements for stability plus flight deck area requirements normally ensure satisfactory landing lane width.

TOTAL CATAPULT AND JET BLAST DEFLECTOR LENGTH — Because the weight of NAVY aircraft continues to increase, the modern aircraft carrier depends totally on the steam catapult for aircraft launch. The catapult length required for launching aircraft is a function of the:

- Catapult power stroke length required to launch the most critical aircraft in the air wing mix.
- Jet blast deflector distance from catapult battery position.
- Aircraft deck run required for aircraft rotation; including wing span.
- Catapult water brake space and structural requirements.

The Jet Blast Deflector is a vital component of the catapulting system. The rapid launching of high performance aircraft is impossible without it. In order to perform the function of protecting aircraft parked aft of the catapult from hot jet engine exhaust, the Jet Blast Deflector must be large enough to accommodate all the various aircraft engine locations and aircraft launch attitudes for the assigned Air Wing mix. At the same time, the deflector attitude should be such as to ensure that the flow of hot gasses is not diverted to the extent that the impinge on the tail surface of the aircraft being launched.

ISLAND AND ELEVATOR LOCATION — The location of island and elevators are also critical design considerations in the flight deck sizing.

The island superstructure in an aircraft carrier becomes prime real estate. Space must be provided for major command and control functions as well as for the Primary Flight Control Station. The island structure cannot be located over the hangar bay since it is not desirable to utilize hangar bay space for uptake routing and the island serves as part of the uptake system in "oil-fired" aircraft carriers. Finally, the island location must be satisfactory from a structural standpoint, provide clear vision for the PRIFLY station, and yet be far enough forward to minimize air turbulence coming off the island into the landing lane.

The aircraft elevators are sized to lift the largest Air Wing aircraft and its associated handling equipment. This is an important point because modern large aircraft can no longer be handled manually. The elevator platform must be large enough in size to permit safe, rapid handling of the largest aircraft. The elevators must be located to serve the catapults during launch and to permit rapid strike-down of aircraft after recovery. Deck edge elevators are normally used in lieu of centerline elevators because they can be operated simultaneously with launch and/or recovery operations, can handle larger aircraft with a given platform size, and require less internal hull volume. The elevators must also be located to allow aircraft coming off the elevator on the hangar deck to turn either fore or aft. Spacing must be such as to insure hull openings satisfy structural and vulnerability requirements. Therefore, the elevator spacing is obviously a function of a complex interaction of arrangements, structural, and vulnerability criteria.

AIRCRAFT SPOTTING AREA — Aircraft spotting area must be provided on the flight deck and hangar deck if the ship is to maintain sufficient payload capability. The hangar bay cannot carry all the aircraft required for normal mission requirements. Thus, sufficient area must be made available on the flight deck in addition to that required for the launch and recovery functions previously mentioned.

The hangar bay is located on the main deck in aircraft carrier design. It normally runs over two-thirds the length of the ship, as shown in Figure 3, and is divided into bays which are separated by fire doors to protect against major conflagrations. In designing for the maximum required flight and hangar deck area, consideration is given to aircraft spot requirements. In addition, the area for ship small boat storage, fire lanes, fire stations, decontamination and wash down stations, and clearance for utilizing ammunition lower and upper stage elevators is also addressed. The hangar bay wing walls are arranged to contain aviation stowages, repair shops, and miscellaneous ship spaces.

Hangar deck height is a critical sizing factor because it affects ship depth. If hangar deck height is insufficient, aircraft handling problems can occur; if too high, wasted area and increased hull weight results. Normally, hangar deck height is sized to provide an optimum "trade-off" between savings in ship weight, ease of aircraft handling and maintenance operations, and ship propulsion plant maintenance requirements. If only one aircraft type drives the height upward,

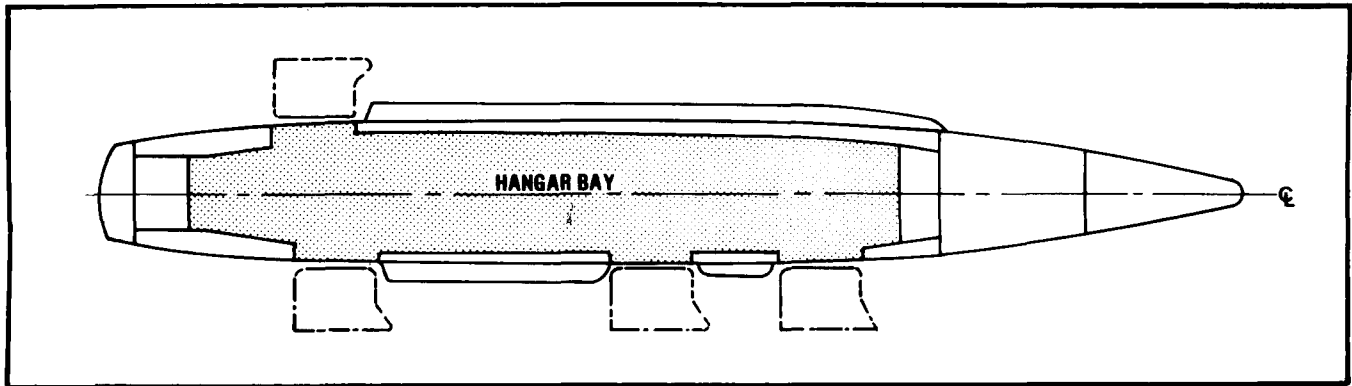


Figure 3. Typical Hangar Deck Arrangement.

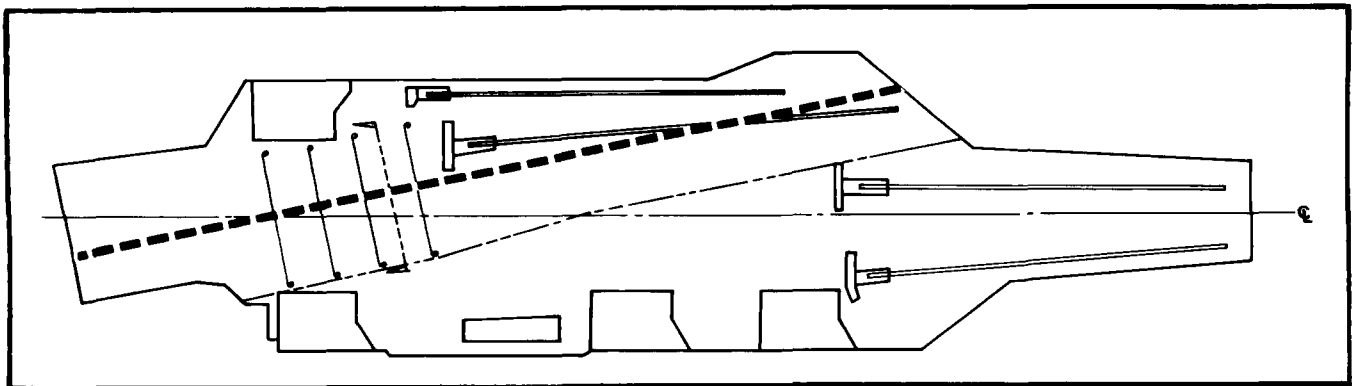


Figure 4. Typical Flight Deck Arrangement.

then a reasonable solution is the installation of a "high hat" area for that particular "worst case" aircraft.

FLIGHT DECK ARRANGEMENTS — The greatest ship interdependencies are found in the launch and recovery facilities associated with the flight deck. This includes not only the catapults and arresting gear, but the aircraft elevators, the flight deck, the landing aids, the jet blast deflectors, and though seldom considered, the location of the uptakes of the propulsion plant on fossil fueled aircraft carriers.

The flight deck of a modern carrier is a functional arrangement of the *four* primary launch and recovery facilities previously described. A typical flight deck is shown in Figure 4. It consists of an angled landing area and an axial launching area. A second launching area is superimposed on the landing deck. The landing area is arranged to:

- Maintain a safe clearance between the tail hook and the ramp as the aircraft crosses the stern.
- Provide adequate wire spacing so as to preclude a double engagement.
- Permit adequate runout after engagement.
- Permit the aircraft to turn and taxi clear of the landing area.

The aircraft glide slope determines the position of the wires relative to the ramp in order to meet the first requirement mentioned above. The second and third requirements are established by characteristics of the arresting gear. The last requirement is again tied to aircraft characteristics.

Sortie Rate

The sortie rate and its associated Air Plan are developed from the mission profile for an operational day. Given this information, the required ordnance and aviation fuel volume can be determined for a given day. Obviously, tankage and magazine volume are major contributors to early ship sizing, and thus these volume requirements must be ascertained in the earliest phase of design. These items are not only a function of the sortie rate but are interrelated to the type aircraft mix used to establish the Air Plan.

Fuel Endurance, Range, and Speed

The ship's fuel endurance, range, and speed are normally defined by the Chief of Naval Operations (CNO) and are a function of mission requirements.

Once established, the ship fuel tankage can be calculated. Naturally, because of the significant volume required for fuel storage, endurance becomes a driving mechanism for a significant portion of ship arrangements; particularly in the hold area.

Just as fuel endurance is a major arrangements driver, so is stores endurance. The requirements for storage are normally as listed in TABLE 4. The Air Wing and ship platform manning drive the total volume of these stores; again major interdependencies exist.

TABLE 4
STORES ENDURANCE

TYPE	ENDURANCE
Dry Provisions	60 days
Chilled Provisions	30 days
Frozen Provisions	60 days
Repair Parts & Equipment-Related Consumables	90 days
Nonequipment-Related Consumables	90 days
Ship's Store Stock	60 days
Medical Stores	60 days

Summary

The Air Wing aircraft complement and mix define the geometry and principal characteristics of the flight and hangar deck as well as the requirements in aviation support, operational, and control spaces. A change in Air Wing mission or complement may redefine many of these requirements and thus change the ship and aircraft compatibility criteria. The various parameters necessary to determine aircraft launch and recovery requirements have been addressed, and their impact on launch and recovery lengths and flight deck geometry assessed. The final proof of a satisfactory arrangement can only be assessed by determining the capability of the Air Wing to perform the assigned mission within the guidelines established. This is accomplished by conducting actual spotting studies that include the following parameters, based on the total operational day:

- Aircraft spotting for servicing, fueling, weapon loading, and pre-launch positioning.
- Final recovery event, initial launch event, total launch and recovery events, total sorties, aircraft elevator cycles, and maximum launch (worst condition) established for the Air Wing.
- Aircraft servicing and starting facilities, their type, number and location

In addition to determining Air Wing operational feasibility, these spotting studies yield fuel and

weapon usage data which can be used to size ship fuel tankage and ordnance magazine volume.

The aircraft carrier's launch and recovery capabilities are directly related to the characteristics of the embarked aircraft. These include not only gross weight, landing weight, take off and approach speed, but also wing span, engine location, take off attitude, recovery attitude and glide slope, tire size, wheel spacing, location of center of gravity, side profile area, and inherent airframe strength. Launch and recovery facilities in turn determine the overall flight deck length and thus influence to a large degree the overall ship size. At the same time these facilities have an important effect on the sizing of the propulsion plant.

AIRCRAFT SUPPORT SERVICES

Aircraft Starting and Cooling Services

Normally these services are provided by use of portable "yellow gear" equipments. Therefore, the designer needs to provide a maintenance facility, stowage area, and fuel storage for this equipment.

LIQUID OXYGEN (LOX), LIQUID NITROGEN (LIN), GASEOUS OXYGEN (GOX), AND GASEOUS NITROGEN (GAN) — These services must be provided as part of the shipboard installation. Space and weight is required for generation plants and storage tanks and HP bottles. Piping distribution systems are required as fixed installations which transfer the products to aircraft service stations.

AVIATION FUEL (JP-5) — In addition to the required tankage for sortie rates and mission profile requirements, the ship platform contains pump rooms containing transfer, service, and stripping facilities. Additional piping systems with filter installations must be provided to deliver the fuel to the topside aircraft fueling stations which are normally located in the hangar bay and on the flight deck catwalk. Tankage is normally provided in the wing tanks of the side protection system and in deep tanks forward and aft of the magazine and machinery armor box.

AIRCRAFT WASHDOWN — The ship's distilling plant capacity must be increased beyond that of other combatants to include sufficient water washdown capability. Transfer systems are required to provide washdown at hose stations located in the hangar bay and on the flight deck catwalks.

ELECTRICAL SERVICES — Aircraft electrical servicing stations are located on the hangar deck

and flight deck in considerable numbers. Each station differs in capacity, but services must be provided for 400Hz, 60Hz, and 28VDC services. In addition, the advent of the new aircraft Type III electrical power, which must be accurate for servicing aircraft, has added increased cost and complexity to previous existing shipboard electrical generating equipment.

YELLOW GEAR — This generic term embraces the various mobile and portable equipment used in aircraft handling and servicing aboard an aircraft carrier. Principal equipments are aircraft tow tractors and tow bars; auxiliary power units for aircraft starting, cooling, and deck checks; crash crane; and a variety of ladders, platforms, dollies, skids, chocks, tie-downs, et cetera, for access to, maintaining, and securing aircraft. Provisions must also be made for maintaining, parking, and stowing all such equipment near its use points on the flight and hangar decks.

Aviation Maintenance System

A measure of the aircraft carrier's operational effectiveness is found in its capability to maintain adequately the embarked aircraft. The modern carrier aircraft is a very complex weapons system. Peak performance in combat of all subsystems, is mandatory. As a result, the requirements for shop, office, and supply support are of import in the design of this combatant ship.

The NAVY divides aircraft maintenance into *three* levels: ORGANIZATIONAL, INTERMEDIATE, and DEPOT. Organizational maintenance involves work performed on the aircraft including daily servicing, inspections, minor adjustments, periodic tests, and the like which do not require shop facilities. Intermediate maintenance is performed in centrally located facilities and involves shop type repair on aircraft components. Depot maintenance, as the name implies, involves major overhauls in industrial type facilities. Both intermediate and organizational level maintenance are performed aboard ship.

The shipboard maintenance facilities can be grouped into *four* major categories:

1) **INTERMEDIATE LEVEL SHOPS** — These include the engine shop, the engine test facility, the structural shop, the hydraulic and pneumatic shop, the tire shop, the non-destructive test shop, the survival equipment shop, the battery shop, and several avionics shops.

2) **ORGANIZATION LEVEL SHOPS** — These spaces are called Aviation Work Centers and are used by squadron personnel to stow special tools, instruction books, records, and various equipment required to service and maintain the individual aircraft.

3) **ADMINISTRATIVE SPACES** — These include a maintenance control center, squadron maintenance offices, an Air Wing maintenance office, and the material control office. The administrative spaces, shops, and work centers are serviced by a special phone system to permit the rapid dissemination of information throughout the widely dispersed maintenance complex.

4) **SUPPLY SUPPORT FACILITIES** — The maintenance operation depends heavily on repair parts support. Performing this function are the supply response and component control office, avionics pick-up and pool issue room, aviation power plants and component issue room, shipping and receiving issue room, automatic data processing room, and key punch room.

DESIGN REQUIREMENTS — In determining the aviation maintenance support requirements, the Air Wing aircraft complement must be considered to define Aviation Maintenance Support Shipboard Requirements.

FIXED SHOPS — In order to determine shipboard Intermediate and Organizational Level Aviation Maintenance Support requirements, it is necessary that an Air Wing composition providing type, model, and quantity of aircraft be established. The Air Wing serves as the "baseline" to determine the applicable common and peculiar support equipment requirements. The single most important factor influencing maintenance space requirements is the variety of systems and aircraft types to be supported.

SUMMARY — The complex modern aircraft requires extensive shipboard maintenance facilities. Aircraft characteristics also determine the hangar height as well as the space required for aviation stores. Thus, the optimum number of aircraft types which may be adequately maintained aboard an aircraft carrier is to some degree a function of the internal space available for the hangar, shops, and storerooms.

Air Launched Weapons Stowage and Handling System

The air launched weapons stowage and handling system consists of the ballistically-protected magazines, which have been sized to meet the mission profile and Air Plan, and their related vertical handling systems. Magazine volume is utilized differently depending on the aircraft ordnance loadout requirements. For this reason, the U.S. NAVY is currently using the universal "tiedown" stowage magazine concept. Magazines are, where possible, located below the waterline and structurally protected from known weapons effects. Main deck spaces adjacent to the lower stage

ammunition elevators must be utilized for the preponderance of inert items.

HANDLING SYSTEMS — The vertical handling system serving the magazines and lower stage stowages normally consist of sufficient weapons handling elevators to provide adequate "strike-up" and "strike-down" rates, and they must serve all levels from the hold to the main deck. Each magazine is designed to provide a pair of end and side loading elevators capable of "striking-down" palletized or containerized weapons and "striking-up" weapons on preloaded Multiple Ejection Racks (MER). In addition, upper stage handling elevators are provided to perform the same function as the lower stage elevators from the main deck to the flight deck. Straight through elevators have not been provided normally for reasons of ship safety. However, recent shipboard modernization has resulted in a straight through elevator installation in the *USS Kitty Hawk* and *USS Constellation*.

DETERMINATION OF WEAPON RELATED SPACES — Study parameters necessary to determine weapon related spaces include:

- "Typical" mission profile or strike plan for specified Air Wing.
- Effect of "worst case" environment (maximum strike effort) study.
- Effect of "minimum" impact (ASW RECON) study.
- Strike Plan study (time and motion to determine A/C weapons loading times).

The results of the studies provide the following:

- Shipfill weapon quantities and ready service weapon quantities.
- Shipboard handling and stowage facilities.
- Type of weapon maintenance, assembly, and check-out spaces required.
- Number, size, and capacities of weapons elevators for weapon "strike-up" in allotted time.

Design Impact

The aircraft carrier's mission is to deliver weapons against sea and shore targets and to defend itself and other friendly forces from air attack. This requires the stowage, handling, and checkout and assembly of a large variety of air-launched weapons. Most of these weapons can be carried aloft by each of the several fighter and attack aircraft types embarked. A few are wedded to a single aircraft. Greatly increased payload and otherwise improved aircraft performance influence

the ship design in many ways. The most important are:

- Magazine stowage volume is increased.
- Replenishment and rearming rates are increased.
- Protection and safety considerations for the magazine are more difficult to attain in the overall ship design process.

The increased magazine volume is related directly to the aircraft payload carrying capacity. It also stems from the fact that the new, more sophisticated weapons such as the guided missiles are less dense than the iron bombs and hence occupy more space per unit weight. Also, certain weapons require special shock mitigated stowages which reduce the magazine stowage density.

The "turn-around" time, or the time required to refuel, service, and rearm modern high performance aircraft, has become an increasingly larger fraction of the total mission time. Hence, the carrier's maximum sustainable strike rate is to some degree determined by the time required to arm the aircraft. Since the temporary stowage of large quantities of weapons outside the protection of the magazine is a hazard to be avoided, a true rearming evolution begins at the magazine and ends at the aircraft. Therefore, facilities must be provided to configure and stow ready service weapons in the magazine and to move them rapidly to the aircraft.

The rearming and replenishment requirements, as explained, stem directly from improved aircraft capabilities. This requires an increase in numbers of larger weapons elevators and a plethora of fixed and portable handling equipments including fork-lift trucks, pallet trucks, bomb-skids, overhead cranes, hoists, and powered loading devices. This growth in size, capacity, and number of weapons elevators has resulted in a reduction in internal stowage space; both inside and outside the magazines. Since the elevators must be capable of handling the weapons in their fully assembled configuration, there exists a practical constraint on the maximum length of individual weapons. Increases in elevator size and capacity to suit new weapons are costly.

The stowage and handling of a large number and variety of aircraft weapons present special ship protection and safety problems. It is axiomatic that larger magazines require extension of the ballistic protection and side protection systems. The advent of the guided missile and special weapons has resulted in the design and installation of new quick reaction sprinkling systems, special atmospheric sensing devices, and alarm systems. These new weapons, particularly in their ready service assembled configurations, present a greater

threat to overall safety than the relatively inert conventional bomb. Care must be exercised to insure that handling equipment and routes do not expose the weapons to accidents which could result in detonation of the explosive or ignition of a rocket motor. Conversely, in deference to the special conditions found aboard ship, the weapons must be designed and proof tested to insure reliability and safety.

SUMMARY — New requirements for the stowage and handling of air-launched weapons result in major changes in ship design. Although current shipboard handling equipment is designed to be as versatile as possible, the physical limitations imposed by the elevators, doors, and hatches place constraints on the maximum size of weapons.

Combat System Configuration

Successful utilization of the capabilities of an aircraft carrier's Air Wing requires rapid effective control of the aircraft movement, launch, recovery, and above all, strike and combat air patrol operations. The key features of an aircraft carrier's combat system can be divided into *three* major categories: *Inter-Communication (IC) and Navigation System*, the *Exterior Communications System*, and the *Combat Direction System and Sensors*.

I.C. AND NAVIGATION SYSTEM — This system consists of all the equipment and systems necessary to communicate vocally between spaces; to distribute ship's motion information to command spaces and electronic systems; to provide alignment reference for ship navigational aircraft gyros; and to provide ship's entertainment.

The key features of any aircraft carrier's I.C. and NAVIGATION SYSTEM must include:

- Closed-circuit television systems providing capability for Pilot Landing Aid Television (PLAT), command briefing, surveillance, monitoring, training, and entertainment.
- Capability for precision alignment of aircraft inertial guidance systems.
- Navigational satellite receivers to maintain accuracy of aircraft alignment.
- Capability for worldwide ship navigation capability (OMEGA).
- Installation of navigational lighting in accordance with the 1972 International Regulations for Preventing Collisions at Sea of 26 July 1973.

EXTERIOR COMMUNICATIONS SYSTEMS — These are normally designed and provided by the Naval Electronics Systems Command and are consistent with the latest in communications requirements planned for the Fleet.

In addition to the required teletype and radio capability, the systems include a:

- Message handling and distribution system capable of processing over 5,000 messages per day.
- Fleet broadcast satellite receiver system.
- Discrete-ship Fleet Broadcast screening capability.

COMBAT DIRECTION SYSTEM AND SENSORS — The Combat Direction System and Sensor System is the heart of any combatant ship. This is particularly true of the aircraft carrier. It is this system that provides all the Command and Control information for ship and Flag decisions. The associated sensors include radars, EW sensors, IFF, aircraft radars and control, and other special combat system facilities.

The key features of the Combat Direction System and Sensor System for which space and weight impact must be addressed are listed in TABLE 5.

TABLE 5

COMBAT DIRECTION SYSTEM AND SENSORS

- A Naval Tactical Data System and ancillary equipment as required for combat direction functions of the ship and embarked Task or Force Commander; appropriate communications equipment for off-ship data handling.
- A long-range, three-dimensional radar with autodetection capability and a very long-range two-dimensional radar.
- An Air Traffic Control and Radar Beacon IFF System.
- A countermeasures intercept, analysis, and deception capability.
- A "close-in" all-weather aircraft landing (talk-down) system providing control of aircraft during approach and recovery.
- A dual channel short-range air navigation system.
- A short-range rapid-fire self-defense weapon system.
- A Tactical Support Center (TSC) which provides computer analysis of acoustic tapes for ASW missions and real-time computer analysis of transmitted ASW helicopter information.
- An Integrated Operational Intelligence Center (IOIC) which requires a significant amount of space. The newer reconnaissance aircraft carry highly sophisticated intelligence-gathering equipment. This in turn has resulted in the installation of automated photo processing and interpretation equipment, pilot briefing facilities, and special handling and maintenance facilities for airborne equipment. In addition, refrigerated storage has been provided for the large quantity of film carried.

In summary, the aircraft carrier Command and Control complex has evolved with the aircraft mix. The crowded flight and hangar decks, the larger aircraft with increased fuel and ammunition capacity, and the expanding servicing and maintenance requirements have combined to make aircraft movement and spotting a complex operation. TABLE 6 provides a list of the typical spaces for which space must be allocated in aircraft carrier design with regard to the combat system function.

TABLE 6
TYPICAL SPACES REQUIRED FOR
COMBAT SYSTEM FUNCTIONS

CIC and Associated Computer Spaces	Flight Control Space
Communications	Radar Rooms
IOIC	Signal Exploration
TSC	Spaces (SEPRAD)
Bridge and Pilot House	IC and Gyro Spaces
Flag Spaces	Metrological Spaces

PLATFORM SYSTEMS IMPACTED BY
AVIATION SYSTEMS

Ship Self-Defense Weapons System

Although it is well recognized that the aircraft carrier's first line of self-defense is its own aircraft and its second line is the escort screen's fire power, there is a necessity to have some form of "close-in" self-defense system to counter those threats which penetrate the already formidable defense environment.

Current U.S. NAVY practice is to install some form of "close-in" weapons support. This can be a CIWS system, BPDMS system, NATO Sea Sparrow System, et cetera, designed and installed so as to give total 360° coverage.

The designer not only must provide weight, space, and suitable arrangement location for the weapons, but also additional facilities that must be provided for the system's ammunition stowage, both magazines and ready service boxes, and adequate ammunition handling facilities.

Constraints on the arrangement of an aircraft carriers self-defense system are severe because of flight deck overhang and possible interference with flight operations. The forward port quadrant is particularly restrictive because of aircraft bolter landings and aircraft launches from the waist catapults.

Flag Facilities

It is essential that an aircraft carrier contain sufficient space to support adequately an embarked Flag Officer and his Staff. The aircraft carrier is the Task Force center for command and control. Therefore, these facilities warrant special design considerations.

KEY FEATURES — The key features in the design of Flag facilities are:

- A Command Center with dedicated communications capability which provides an integral facility for the Task Force Commander.
- A Display and Decision Area which provides a capability for real-time overall tactical situation review.

- An Operations and Analysis Facility to permit corollary Staff functions such as detailed operational planning and development, intelligence assessment, et cetera.

Personnel Support and Habitability

The aircraft carrier must be designed with facilities to operate, service, and maintain the embarked aircraft, and to provide space to house the embarked Air Wing and Flag personnel. This requirement has a great impact on aircraft carrier design.

Since 1965, the NAVY has had a major program to improve ship habitability. Minimum standards for shipboard accommodations have evolved. These cover not only berthing spaces but sanitary, messing, laundry, and recreation facilities. In addition, minimum requirements are specified for heating, ventilation, and fresh water stowage and production. Approximately 28.0 square feet of deck space are required for berthing, messing, and sanitary facilities for *one* enlisted man. For CPO's this is 48.0 square feet per man, and for Officers this is about 86.5 square feet per man. Assuming six feet six inches for stowage height, provisions for *each* man requires about 5 square feet of space. These figures do not include the additional space required for ventilation, air conditioning machinery, evaporators, and fresh water tankage.

Maintaining the needs of Air Wing and Flag personnel requires additional support in the form of services. For example, medical and dental facilities are sized to meet total ship accommodations as are ship's offices, disbursing offices, and other administrative spaces required to maintain the records of NAVY personnel.

Air Department and Air Wing Spaces

The Air Wing personnel complement is derived from the number of Squadron and Detachments and the aircraft types and numbers that are assigned to the Air Wing. Requirements for ready rooms, flight suit rooms, and Squadron offices,

TABLE 7

AIR DEPARTMENT & AIR WING SPACES

Primary Fly Control	Squadron Flight Suit Rooms
Aviation Maintenance Control Center	Squadron Offices
Crash and Salvage Team Locker	Flight Deck Gear Lockers
Flight Deck Control	Hangar Deck Gear Lockers
Hanger Deck Control	Flight Deck Crew Shelters
Air Department Office	Squadron Work Centers
"V" Division Offices	Flight Suit and Parachute Area
Air Wing Offices	Aviation Ground Support
Squadron Ready Rooms	I.C. Engine Shop
Catapult Machinery Spaces	Flight Deck
Arresting Gear Machinery Spaces	Hangar Deck

therefore, can significantly change with a change in Air Wing composition. The Air Department is staffed, however, with permanent ship's company, and the requirements for space do not vary. Spaces which are normally considered as part of the Air Wing or the Air Department are listed in TABLE 7.

Ship Protection and Structural Design

Aircraft carrier design requirements for survival and damage control are unique in certain respects while employing standard NAVY ship structural and protection criteria in others.

SHIP PROTECTION —

Fire — The fire fighting system includes those features and facilities which have proven to be most effective in previous aircraft carrier designs. Automatic systems are normally installed where appropriate. In addition, adequate access routes to all compartments for fire fighting parties and escape routes from all areas where personnel might be entrapped are provided.

Blast — Over-pressure design thresholds are established for the ship structure and for major topside equipments such as radar antennae and weapon systems. These criteria are established normally as the result of cost-utility "trade-offs."

Shock — Both underwater and air shock wave intensity are considered in the design of the ship.

Nuclear, Biological, and Chemical — A portable or fixed radiac monitoring system is normally provided as well as a nuclear contamination countermeasures washdown system.

Structural, Ballistic and Torpedo Side Protection — An aircraft carrier is a high option target and as such is protected to a greater extent than most surface combatants.

Topside Fragmentation Protection — Topside fragmentation protection is provided for the island structure and for exposed electronic and ancillary equipments.

STRUCTURAL DESIGN REQUIREMENTS — Numerous confidential data exist on the structural design of aircraft carriers and are available to any organization involved in such a design. The list provided in TABLE 8 is a general *unclassified* summary of the types of considerations which must be addressed in the design.

Bents — The term "bents" refers to the main transverse members above the main (hangar) deck, in way of the hangar, which support the flight and gallery decks. The bent legs, which extend between

TABLE 8

BASIC CONSIDERATION IN AIRCRAFT CARRIER STRUCTURAL DESIGN

- The flight deck, gallery deck, hangar deck, and decks above the main machinery box must be protected decks.
- The installed side protection system should be adequate to localize damage from SSM's.
- Magazines should be below the waterline.
- Main propulsion spaces must be arranged so that at least two major conventional hits will be necessary to immobilize the ship when the side protection system is being maintained satisfactorily. This criterion is based on a prediction of the extent of damage from various assumed warhead sizes as obtained from an analysis of anticipated weapon threats.
- A flooding system must be provided for selective counter flooding in order to restore list, trim, or stability after damage.

the hangar deck and the gallery deck, appear as transverse bulkheads outboard of the hangar side bulkheads. The transverse girder between the gallery and flight decks is formed by a transverse bulkhead which extends from shell to shell. Due to the large spans and high loads, the bents are highly stressed and require special design considerations.

Island Structure — The Island Structure of an aircraft carrier requires certain structural design considerations *not* found in other naval ship designs. Islands are generally very tall, narrow structures for which side loads constitute the critical design factor. A system of transverse bulkheads, normally called "shear bulkheads", are provided to resist this type loading. Shear bulkheads must be in the same transverse plane and be continuous from the bottom to the top of the island.

Seakeeping

Aircraft operations superimpose critical ship design seakeeping requirements on the aircraft carrier, over and above usual naval design norms.

Hull motions must be minimized in aircraft carrier design; the most limiting factor being vertical displacement at flight deck ramp. Hull motions translate to ship machinery and equipment requirements. Therefore, equipments must be capable of operating satisfactorily under the conditions shown in TABLE 9.

TABLE 9

SHIP MOTION AND ATTITUDES EQUIPMENTS AND MACHINERY OPERATING REQUIREMENTS

- When the bow or stern is trimmed down permanently by 5° from the normal horizontal trim.
- When the ship is permanently listed up to 15° to port or starboard.
- When the ship is pitching up to ± 10°.
- When the ship is rolling up to ± 30°.

IMPACT OF MOTION ON AIRCRAFT RECOVERY —

The motions of an aircraft carrier are extremely critical since a limiting vertical displacement at the flight deck ramp exists which, when exceeded, forces termination of flight operations. The designer must try to limit hull motion and such in order that air operations can be conducted a considerable percentage of time at sea.

IMPACT OF MOTION ON AIRCRAFT HANDLING —

During flight operations, aircraft must be moved from the flight deck to hangar deck and vice versa. During rough weather, elevators can become slick from salt water spray. Although this is mainly interrelated to freeboard to hangar deck criteria, wetness is enhanced as ship motion increases. The designer must consider a criteria of aircraft taxiing, handling, launch, and recovery up to Sea State 5 and, as such, attempt to control ship motions to ensure such operation is feasible.

Machinery Plant Features

PROPULSION PLANT — The ship's propulsion plays a vital role in launch and recovery operations. Under no wind conditions, an aircraft carrier operating at 30 knots creates a relative wind speed of like amount. Thus, an aircraft requiring a 120 knot take off speed needs only 90 knots end speed from the catapult plus a suitable safety margin. Likewise, the arresting gear on the same 30 knot ship sees only a relative speed of 120 knots for an aircraft approaching at 150 knots. Thus, the ship's maximum speed capability becomes a significant factor, particularly for aircraft on which structural limitations prevent utilization of the maximum energy capabilities of the catapults and arresting gear.

Steam Consumption — The aircraft carrier, unlike other surface combatants, must be able to produce sufficient steam to attain required ship speed and have sufficient steam capacity to provide charging of the steam catapults. This reserve capacity must be sufficient to ensure catapult launch sequence and be maintained without dragging steam from the turbine steam supply. This steam requirement becomes more pronounced in that it must have proper enthalpy. Thus, design of both the steam and catapult system will vary with the type power plant; i.e., nuclear or fossil fueled.

Damage — The propulsion plant must be designed such that damage to a shaft still permits operation of aircraft.

ELECTRIC PLANTS —

Electric Generating Plant — Because of the heavily increased requirements for 400Hz and 60Hz power for direct and interrelated Air Wing support, an aircraft carrier requires much more power generating equipment than most combatant ships. In addition, there is a design requirement to supply maximum functional load (cruising with air operations) with one generator out of commission.

Emergency generators must be provided in sufficient quantity to offset the possible loss of generators in a machinery space and still ensure capability to supply full functional load. A final requirement is that the emergency plant must provide for emergency ship control and limited air operations upon the loss of all main ship service generators.

The designer must satisfy the above operational load requirements by selected general arrangements to ensure adequate separation of units for maximum battle damage protection.

Areas of Concern to Designer — Historically, electric load requirements have grown in aircraft carrier design and there is no reason not to expect a continuing growth in certain areas as aircraft size and combat systems capability increase. Areas of potential growth which must be assessed are:

- Additional fire pumps for increased fire protection and water supply to increase area of jet blast deflectors.
- Anticipated increased aviation support loads including increase in flight deck service and increase avionics shop loads.
- Continuing increased air conditioning loads due to an increase in environmental control required for sophisticated combat system units, computer centers, et cetera.

DISTILLING PLANTS — An extremely high capacity distilling plant is required because of the aircraft washdown requirements and the increased Air Wing manning which impacts upon the numerous services which require water such as laundry, scullery, et cetera.

FIREFIGHTING SYSTEMS — The combination of aircraft, aviation fuel, and aviation ordnance create the potential for catastrophic conflagrations in an aircraft carrier. It is, therefore, extremely important that maximum firefighting protection be included in any such design. Typical firefighting systems which should be designed into any aircraft carrier are as follows:

Firemain — A horizontal loop system arrangement located above the damage control deck

and supplied by a combination of steam turbine driven and motor driven fire pumps should be installed. Pumps, segregation valves, pressures and alarms should be remotely monitored and controlled.

Aqueous Film Forming Foam (AFFF) — This system should be installed in the hangar bays, bilge regions of machinery spaces containing flammable liquids, and trunks of elevators having openings to the hangar bays. Normally, the flight deck countermeasures washdown system can be used for foam coverage of flight deck fires. AFFF hose reels should be appropriately located on the hangar deck and flight deck catwalks.

Halon 1301 — This system should be used to protect non-bilge levels of machinery spaces containing flammable liquids, flammable liquids' issue and storerooms, flammable gas storerooms, diesel generator enclosures, paint mixing and issue rooms, and aviation lube oil storerooms.

Portable 15 Pound CO₂ Extinguishers and Dry Chemical Extinguishers — These should be installed in shops, repair stations, CONFLAG stations, electronic or navigational areas, galleys, machinery spaces, filter rooms, and rooms containing electrical motors, switchboards, and panels.

Steam Smothering System — This type system should be provided for protection of boiler air casings, steam catapult troughs, steam catapult launch value enclosures.

CONCLUSION

The interrelationships between the aircraft carrier and its Air Wing are numerous and

complex. These interrelationships manifest themselves to some degree in all the significant characteristics of the ship including the hull size, the propulsion plant, the electronics suite, and the degree of protection provided.

The significant improvements in combat effectiveness of carrier aircraft have for the most part dictated increases in carrier size. The flight deck is longer to accommodate the launch, recovery, and aircraft handling systems. The hangar and associated aviation shop spaces have increased in order to adequately maintain the aircraft. Stowage handling facilities for aviation weapons and fuel loads of the modern aircraft have been expanded. Command and Control facilities have advanced to meet requirements dictated both by the threat and the capability of the aircraft. Finally, the many supporting functions which must be performed by the ship, including provision of accommodations for the Air Wing and Flag personnel, require more internal hull volume, more electrical power, and more complex equipment.

However, it still may well be possible to reduce the size, and therefore the cost, of our aircraft carriers simply by having our Naval Aviation Aircraft Planners try to design to minimize the different types of aircraft (possibly four instead of eight or nine) which are to be handled and maintained on board. This would contribute immensely to a partial solution for reducing aircraft carrier size and volume requirements which have been discussed in this paper. It is obvious that aircraft type and loadout are the major parameters which impact the aforementioned design requirements, particularly in the areas of crew space, avionics support, flight deck sizing, and required launch speed; to name but a few.



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