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FLIGHT DECK DESIGN GUIDELINES

THE AUTHOR

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ABSTRACT

Aircraft carrier flight deck design is the result of a long iterative process which involves many complex and often subjective decisions. The process is basically a trial and error effort to integrate many diverse functions into an operationally satisfactory flight deck that is compatible with below decks arrangements. This paper attempts to delineate the rationale for these decisions.

Those aspects of aircraft carrier design related to the aircraft/ship interface as they apply to the flight deck are described in detail. This paper does not offer pat solutions to problems of flight deck design, but reports the operational experience gained with past Aircraft Carrier designs and discusses problems which must be addressed in the design of new aircraft carrier flight decks.

INTRODUCTION

AIRCRAFT CARRIERS RESULT FROM A MILITARY REQUIREMENT for a mobile, waterborne, tactical airfield capable of supporting sophisticated military aircraft in a hostile environment. The goal of the ship designer is integration of those functions necessary to support the military function into a comparatively compact package which can safely perform the mission.

If the same military requirement were met by using a landbased site, those functions which pose a hazard to each other or which have little compatibility could be dispersed widely. The design problem is integration of these functions into the confines of a ship, while allowing smooth operation during high stress level periods. Not only must those functions which have limited compatibility function smoothly, but ideally no single function should pose a hazard to its neighbor should an incident or accident occur. On land one probably would not build an airport on top of a city which is on top of a munitions complex. At sea the designer is forced to do just this.

GENERAL CONSIDERATIONS

Aircraft carriers with different operational requirements may have quite dissimilar numbers and arrangements of major subsystems. The aircraft complement is the basis for determining many of the Flight and Hangar Deck characteristics and is important in sizing most of the flight deck subsystems. Any specific mix of aircraft also affects, directly and indirectly, many of the decisions made during the design process. On the Flight Deck, such decisions may include consideration of aircraft maintenance, refueling, traffic flow and parking for various operational situations, flexibility for different aircraft mixes, and minimizing the restrictive effects of damage from heavy seas or wind.

In arranging the Flight Deck, a constant series of checks and compromises with the requirements of the lower areas of the ship must be made. In many respects this is the most complex and subjective aspect of laying out a Flight Deck, often evolving into a seemingly endless spiral of iterations. With each different ship, various factors will assume different relative levels of importance. The following is a brief discussion of some of these interactions that require consideration.

The location and size of the hangar must be compatible with the location of the aircraft elevators.

The location of the after hangar bulkhead(s), in most recent carriers, has been determined by the size of the jet engine shop, aircraft structures shop, and related functions, which are located in the stern. The avionics shops on the other hand require a more vibration free location and are therefore located forward.

The forward hangar bulkhead is usually an extension of the forwardmost (or next aft) main transverse bulkhead bounding the forwardmost magazine complex. This has been done to allow the lower stage weapons elevators to open directly into the hangar for "strikedown" to the magazines and to allow the Hangar Deck to be used as a transfer area during "strikeup" operations. Weapons elevators should not interfere with aircraft operations or maintenance. If multi-stage elevators are used, transfer of ordnance between stages should be direct, close coupled, and unobstructed.

The run of uptakes between the machinery box and the Island requires care and compromise to minimize duct length and turns and yet not interfere unduly with access on intervening decks.

For nuclear powered ships, access for "recoring" must be provided.

Support must be provided for such heavy concentrated loads as the Island, catapult troughs, catapult holdback structure, catapult water brake, jet blast deflectors, and the integrated Catapult Control Station.

For satisfactory operation, many of these subsystems require precise alignment, and the design of their structural support systems requires special attention.

Structural discontinuities, such as openings or breaks in the shell, lower decks, and bulkheads are implicit in the location of many Flight Deck components such as aircraft and weapons elevators. The structural effects of such openings, individually and in combination, must be assessed and compensation, either by increased scantlings or relocation of the opening, provided.

The Flight Deck configuration must be compatible with the ship's self-defense weapons systems. There are also interactions with "ship" functions such as line and anchor handling and replenishment at sea stations.

The placement and number of aircraft elevators, weapons elevators, catapults, arresting gear, and other vital functions must be critically evaluated from the standpoint of net ship vulnerability to the effects of weapons attack.

The foregoing is a sampling of the more important of the many interactions that influence the design of a Flight Deck.

Aviation Features Considerations

To understand the rationale for aircraft carrier design it is necessary to have some knowledge of the design requirements from the viewpoint of both the engineer and the user. To accomplish this objective each aviation subsystem will be described both functionally and in engineering terms. Operational constraints are discussed where appropriate. Those subsystems and physical constraints which dictate the character of the Flight Deck of an aircraft carrier are as follows:

- Recovery Area.
- Launch Area(s).
- Island Structures.
- Aircraft Elevators.
- Safe Parking Areas.
- Aircraft Services.
- Weapons Services.
- Self Defense Systems.
- Fire and Nuclear Biological Chemical (NBC) Protection.
- Accesses.
- Construction Constraints.
- Seakeeping Considerations.

Recovery Area

As the aircraft approaches the ship from the stern the pilot leaves the counter-clockwise approach pattern and aligns his aircraft with the stripes marking the recovery area. The aircraft at this time is in a "dirty condition," i.e., flaps, gear, and hook down. Assuming an aircraft requires 140 knots approach airspeed and that a natural surface wind of 20 knots is blowing from bow to stern, plus a 20-knot ship speed, the relative velocity between ship and aircraft is 100 knots or 169 feet per second.

The aircraft is assisted to the touchdown point on the deck by the Visual Landing Aid (VLA) System which provides the pilot with a visual reference for 3.5° *negative glide slope* along the landing area centerline. Perfect adherence to this angle provides an 11-foot clearance between the aircraft tailhook and the ramp (round down) of the recovery area with touchdown 180 feet forward of the ramp. In addition, the aircraft may land 20 feet to port of the recovery centerline while parallel to the recovery centerline, or may deviate a maximum of 7° to port from the recovery centerline if the aircraft tailhook engages the last (forwardmost) arresting wire.

Theoretically the tailhook impacts just before, or aft of, in relation to the ship, the second or target arresting wire (cross deck pendant) which it engages. The tailhood unwinds the wire (Purchase Cable) from the arresting engine. The arresting engine is adjusted to a predetermined resistance for each aircraft type and its gross landing weight.

Each aircraft is either tailhook or arresting gear limited for its maximum allowable landing (trap) weight, i.e., it has a maximum (hit) engagement speed with the arresting wire based upon gross weight and landing gear and tailhook limits. The arresting gear type and wire runout distance determine whether a particular aircraft is arresting gear or tailhook limited. A major factor determining the arresting gear selection is the ability of the ship to make its own "Wind-Over-Deck" on a still air day.

When the aircraft is stopped on the deck, the arresting wire is nearly fully extended. If the wire does *not* drop clear of the tailhook on normal roll back after the aircraft is stopped, the arresting gear operator and/or the "hook runner" will disenage the wire.

When the arresting wire is clear of the tailhook, the aircraft is moved to an area outside the recovery area. For this maneuver, which involves aircraft turnaround, and for tailhook disengagement, an area *forward* of the arresting area is required.

Should the aircraft miss all of the arresting wires ("Bolter") or should the arresting equipment fail, one of two things will occur. The pilot will accelerate the aircraft sufficiently to regain flying speed or the aircraft will run over the forward end of the recovery area and crash into the sea.

An alternative landing method to the normal arresting wire landing is the barricade landing. Barricade landings are used only when the aircraft can neither make a normal landing nor be diverted to a land site. The barricade, consisting of a net of nylon straps, is stretched between two stanchions in similar fashion to a tennis net. The stanchions are located farther toward the bow than the "hook touchdown" point to give the pilot a greater opportunity to engage the barricade since the aircraft may not be capable of completing a normal arrestment or attempting a second pass. As the pilot flies the aircraft into the barricade, it wraps itself around the aircraft wings, detaches itself from the stanchions, and tension is applied to the arresting engine's cables. The cable retardation ("run-out") setting is different from a normal tailhook arrestment as is the total deck "runout." Aircraft disengagement from the barricade is more time consuming than tailhook disengagement. Therefore, barricade arrestment and

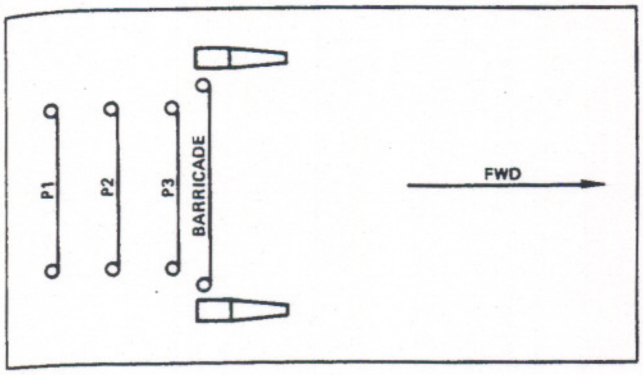


Figure 1. Typical Three-Wire Plus Barricade System.

disengagement combined with barricade rigging prior to engagement and rerigging after, represents a recovery disruption. During barricade arrestment, "Tankers" may be required for in-flight refueling of other airborne aircraft. Barricade arrestments require the aircraft to be aligned with and centered on the landing area centerline.

The turnaround distance and barricade stretch distance must be adjacent and accessible to an area which provides personnel and aircraft safety after recovery, i.e., a safe parking area.

The first requirement for layout of a recovery area is arrangement of the arresting gear wires in relation to each other and to the after ramp. As aircraft carrier pilots and equipments have evolved to the present degree of sophistication, the number of wires and barricades has decreased. Today's Fleet Carriers have either three or four arresting engines plus a barricade engine. Figure 1 shows a typical three wire plus barricade system.

The spacing between wires in a fore-aft direction has been optimized at 40 ± 5 feet. This spacing minimizes both hook bounce, which could result in a "Bolter," and double wire engagements, which could damage the aircraft. The greater the spacing the more likely that hook bounce will occur; the closer the wires, the more likely that a double wire engagement will occur.

The wire span (athwartships spacing between deck sheaves) is a function of the dynamics of the system and is determined by the amount of arresting wire "runout," the minimum acceptable wire angle on the tailhook, and the load exerted on the wire by the aircraft velocity and weight. The span for a particular ship is determined by the dynamics of the aircraft which are expected to be part of the Air Wing operating from that ship.

Forward of the arresting wires, space must be allowed for the aircraft to pull the arresting gear wire to its maximum payout distance ("runout"). The cross deck pendant is attached to a Purchase Cable on each side of the arresting area with clevis pin poured-socket connectors. As the tailhook engages the cross deck pendant and starts to reel out the Purchase Cable, the connection on each side is slammed to the deck. Impact pads must be provided on the deck to prevent damage to the connection. The distance between the deck pendant in its static position and maximum "runout" can vary from 250 feet to 350 feet, depending upon individual aircraft requirements and the ability of the ship to produce its own wind over the deck during zero ambient wind conditions. At maximum "runout" either the turnaround criteria or the barricade stretch will determine the landing area length.

Flight decks of Aircraft Carriers have been constrained to a 126-ft clear limit line to port and starboard of the ship centerline for permanent structure because of drydock limitations. To accommodate the port deviation landing (max. 7° from recovery area) a hinged extension beyond this limit is sometimes attached to the permanent deck edge. This extension is not necessarily hinged in the same sense that the wings of naval aircraft are, but it must be physically removable without cutting steel. Such installations are complex and costly, and are avoided if possible.

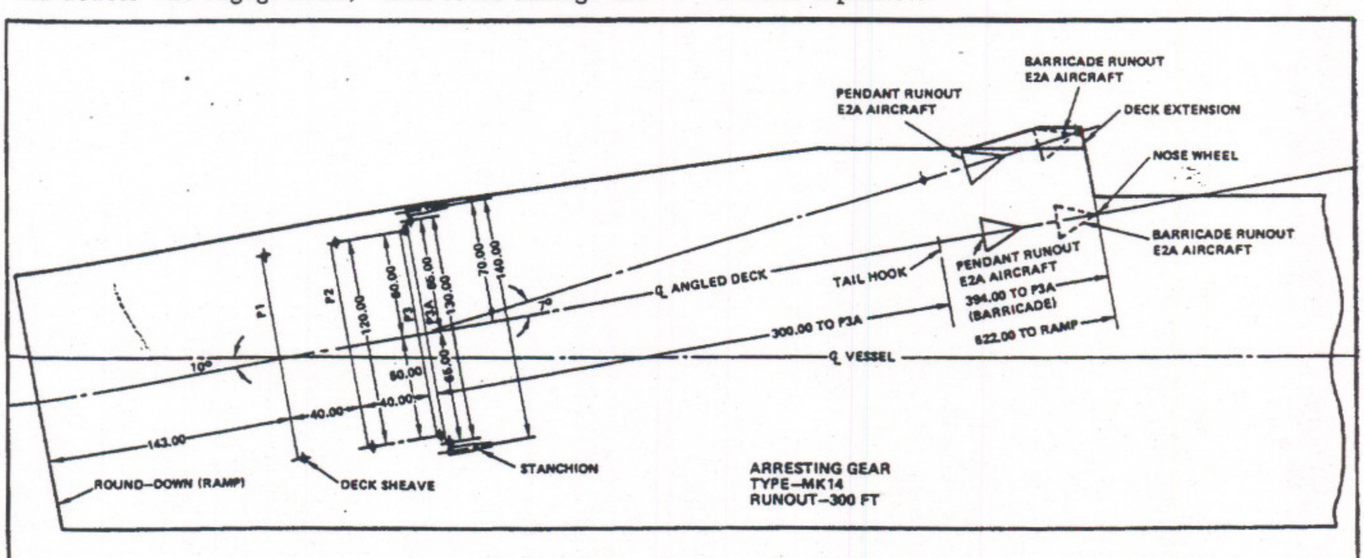


Figure 2. Arresting Gear, Type-MK14.

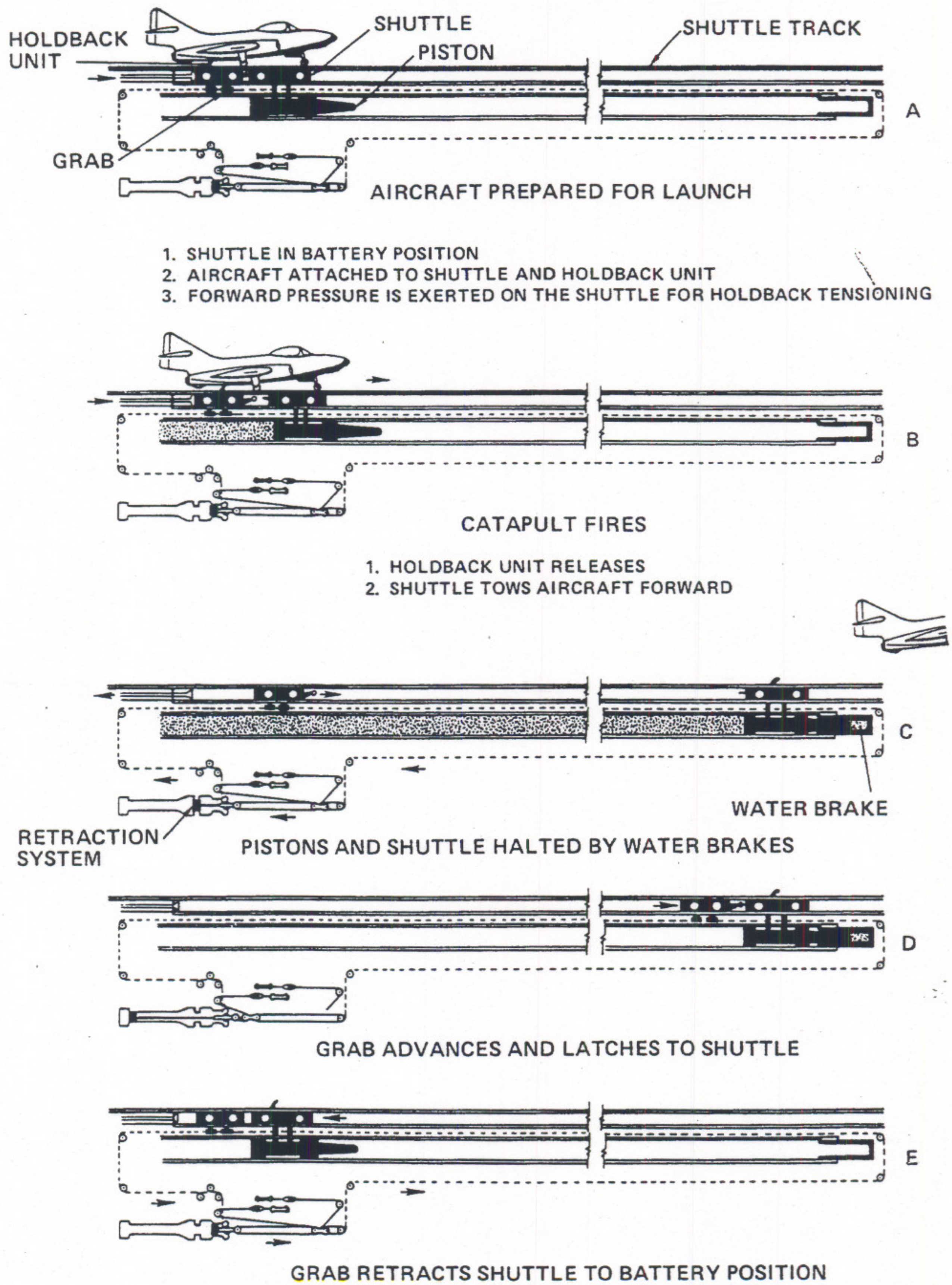


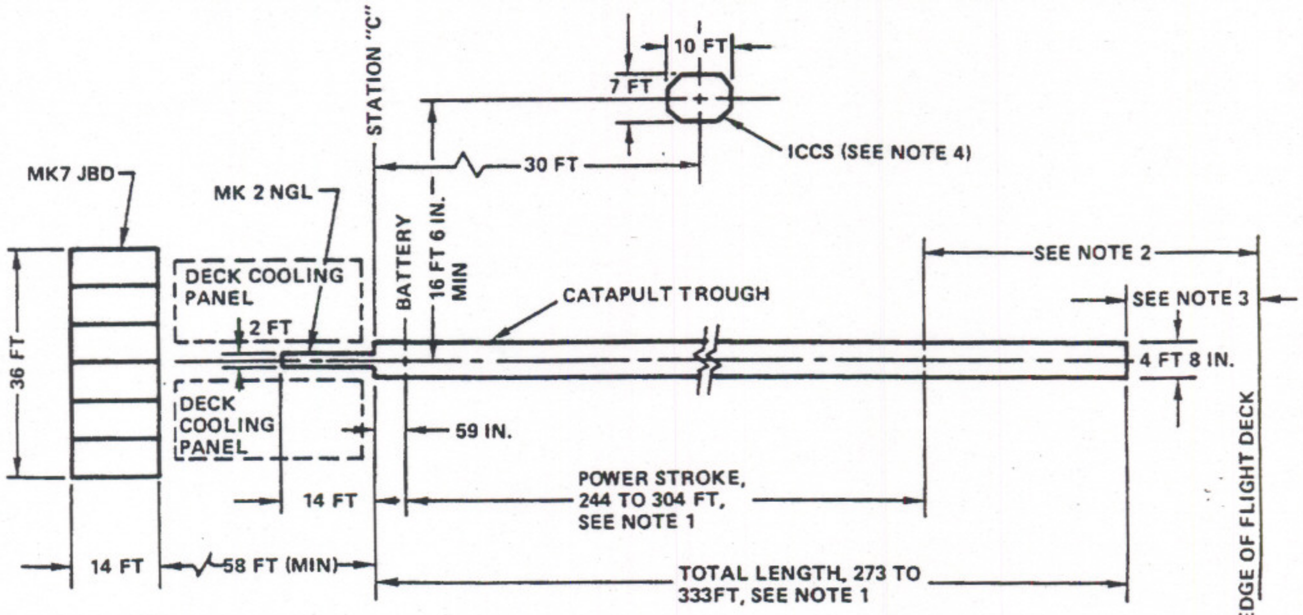
Figure 3. Catapult Operation.

Figure 2 is an example of a typical recovery area. This example illustrates only the deck area requirements for arrested and barricade recoveries. The angle of the forward ramp is important for aircraft being recovered normally and for "Bolters," since the forward sponson edge can produce an undesirable degree of turbulence if improperly designed. For each ship design, turbulence must be minimized while adhering to the other recovery area criteria. The stern ramp is perpendicular to the recovery area centerline.

A "Bolter" is an aborted arrestment. There are *two* extremes, with an infinite number of conditions between them, which may describe a "Bolter." The *safest* type occurs when the tailhook misses all of the wires, the aircraft has not decelerated, and can become airborne again before reaching the end of the recovery area. The *most dangerous* "Bolter" occurs when engagement with a deck pendant is made and for some reason (deck pendant failure, tailhook failure, et cetera) the aircraft is released after decelerating below flying speed. In the latter case it is impractical to provide sufficient deck length for the aircraft to become airborne again. Those cases which fall between the extremes require special treatment. This special treatment is provision of clearance forward of the landing area so that any aircraft which "bolters" and sinks ("Bolter Sink") below the Flight Deck level will have a clear path at a *negative* 15° angle from the horizontal toward the water. For angle deck ships, such as *USS Nimitz*, this means providing a large enough angle between the recovery area centerline and the ship centerline for the aircraft's starboard wing tip to clear the port forward Flight Deck edge as the aircraft sinks below the Flight Deck level. This clearance isnecessary to prevent an aircraft, which can regain flying speed after sinking beyond the forward landing ramp, from hitting the ship and crashing rather than regaining flying speed and landing on a second attempt.

Launch Area(s)

As the aircraft taxies to the catapult, the Jet Blast Deflector (JBD), which was raised for the previous launch, is lowered. As soon as the aircraft's tail clears the JBD, the JBD Operator raises the deflector panel. The Aircraft Director leads the aircraft to the station zero position. The Catapult Crew attaches the nose wheel launch bar to the catapult shuttle and the "holdback" to the deck. Steam pressure is applied to the shuttle at the battery position which tensions the "holdback" link. During the time the aircraft is being attached to the catapult, the aircraft weight is verified by the pilot and catapult personnel. This data is relayed to the Catapult Control Station, while other Flight Deck



NOTES:

1. OPTIMUM POWER STROKE (AND TOTAL LENGTH) DEPENDS UPON FINAL SELECTION OF AIRCRAFT TYPES AND VESSEL SPEED. DIFFERENT POWER STROKES ARE REQUIRED AS A FUNCTION OF AIRCRAFT TYPES AND WIND OVER DECK.
2. RECOMMEND 35 FT MINIMUM OF FLAT DECK FORWARD OF END OF POWER STROKE FOR A/C ROTATION.
3. DISTANCE FROM BUTTRESS PLATE TO FORWARD EDGE OF FLIGHT DECK DEPENDS ONLY UPON A/C ROTATION AS DESCRIBED IN NOTE 2 AND THE SHIP'S STRUCTURE REQUIRED TO SUSTAIN CATAPULT BRAKING LOADS.
4. ICCS LOCATION SHOWN IS FOR TWO BOW CATAPULTS.

Figure 4. Illustrative Example of Launch System.

personnel remove the red flagged safety pins, which would dud an inadvertent weapon release, from the aircraft's ordnance.

After attachment to the catapult, the aircraft engines are accelerated to the full military power setting and the aircraft strains against the "holdback" while the shuttle pulls forward on the nose wheel, Figure 3. The pilot and Catapult Officer agree that the aircraft is ready for launching and the launch signal is given. Steam pressure on the shuttle is increased, which breaks the "holdback" link, and the shuttle, towing the aircraft by the launch bar, accelerates to flying speed over the catapult length in about 2 seconds. When the shuttle reaches the end of the power stroke, a water brake stops it in 5 feet of forward travel. As the shuttle stops, it releases the launch bar which allows the nose wheel strut to extend from its compressed position thus rotating the aircraft from its nosedown launch attitude to the predetermined "take-off attitude" peculiar to each aircraft type.

The aircraft launching function is generally accomplished using catapults to supplement the ability of the aircraft and the ship to provide sufficient wind speed relative to the aircraft for sustained flight. For each specific aircraft, a different minimum air speed is required depending on "take-off" weight, stores configuration, and ambient temperature. The catapult system must, therefore, be designed to accommodate the worst case aircraft in its heaviest configuration. This then determines the minimum length for the power stroke of the catapult.

Jet Blast Deflectors (JBDs) are located just aft of the aircraft launch position as shown in Figure 4. These are sea water-cooled deck panels which can be raised to a sufficient angle to deflect upwards the exhaust gas of an aircraft being catapulted. These gases must be deflected to:

1) Prevent compressor stall and/or "flameout" on the engines of aircraft awaiting launch immediately behind the catapult.

2) Prevent the exhaust gases from damaging the Radomes of aircraft awaiting launch immediately behind the catapult.

3) Prevent ignition of explosives or rocket motor grains on aircraft immediately behind the catapult by hot gas impingement.

4) Protect Flight Deck personnel between aircraft in the launch position and those awaiting launch.

The JBD is located sufficiently behind the catapult to accommodate the worst case aircraft expected to be launched, as regards exhaust gas temperature, direction, quantity, and the worst case aircraft to be protected behind the JBD.

Sea water-cooled Deck Cooling Panels are located forward of the JBDs to cool the deck areas heated by the deflected jet engine gases. These Cooling Panels provide reasonable deck temperatures for subsequent aircraft/catapult hook-up and aircraft weapon arming.

The catapult and its associated systems have the following location constraints which should be applied as stringently as possible:

1) The catapult longitudinal centerline must lie inboard of the flight deck side sufficiently to preclude a main gear wheel dropping off the deck edge during launch. Two feet is nominal wheel to deck edge clearance.

2) The catapult longitudinal axis should be as close to being parallel with the ship's longitudinal centerline as possible. A maximum deviation of 6° is allowed.

3) Jet Blast Deflectors, where possible, are kept out of the landing area to preclude a fouled deck caused by failure in the UP position. Where it is necessary to have catapults in the landing area, as in the case of the four catapult ship, the JBD erection system should have a quick-release *manual* lowering system.

4) When catapults must be installed in the landing area, the arresting wire/catapult trough interface must be designed to preclude catching the arresting wire in the catapult trough at full "runout," thereby damaging the wire.

5) The forward edge of the Flight Deck must be far enough forward of the launching system to provide the necessary aircraft rotation distance, or to provide sufficient depth for the retardation structure to absorb the load transmitted from the water brake, whichever is greater.

Island

The Island contains a variety of services which are related to the Flight Deck and which are required to be located at or above the Flight Deck level.

For a fossil fueled ship, the Island contains the intakes and the uptakes for the propulsion system and its location must, therefore, take into consideration the routing of these ducts. An alternative is the "side pipes" used by Japan during World War II which were lowered below Flight Deck level during aircraft operations.

The Island location, size, and shape can affect aircraft during recovery. The stacks for a fossil fueled ship are a potential source of smoke which can partially obliterate the pilot's view as he lands. The aerodynamics of the Island determine the severity of the turbulence through which an aircraft must fly during recovery. The flow around the island and the flow of exhaust gases are investigated by model test during design.

The Island's existence makes it a prime platform for electronic emitters, and as many as possible of the ship's antennas are installed on it. Island real estate has become so saturated with antennas that more recent Aircraft Carriers have required the addition of a tower on the Flight Deck to accommodate all of the emitters.

The panoramic view from high on the Island is ideal for the Pilot House (Ship's Bridge) and the Flag Bridge. Visibility from the Pilot House must be such that the Commanding Officer can conn the ship, oversee flight operations, and conduct underway replenishment with ease.

Primary Flight Control ("Prifly") must be located on the Island above the Flight Deck in a manner which enables the Air Officer and his assistants to control flight operations. A panoramic view of the whole Flight Deck is desirable to enable "Prifly" to coordinate launch, recovery and movement of aircraft safely.

Flight Deck Control is normally located on the Flight Deck level within the Island to enable the Flight Deck Officer to control flight deck traffic and be readily accessible to the Aircraft Handling Officer.

The Aviation Maintenance Center is also normally located in the Island on the Flight Deck so as to be accessible to Squadron maintenance personnel.

The base of the Island also serves as an air terminal for passengers, mail, and freight because of its convenient location.

To perform most of its aircraft-related functions the Island should, ideally, be centrally located on the Flight Deck. Since this would interfere with air operations the Island has traditionally been located adjacent to the starboard Flight Deck edge near midship.

Aircraft Elevators

Aircraft elevators are required to "cycle" aircraft between the Flight Deck and the Hangar Deck. Supplementary tasks include moving aviation ordnance to the Flight Deck and "striking down" Vertical Replenishment (VERTREP) Stores and ordnance to the Main Deck. During air operations, aircraft ready for flight are "cycled up," while those requiring maintenance are "cycled down."

Elevators on early Carriers were located within the shell of the ship. This design protected the aircraft fairly well from spray. However, the following disadvantages pointed the way to *deck edge* aircraft elevators:

• Increases in aircraft size require total ripout and major structural modification to install a larger elevator.

• When the elevator is down, there is a large opening in the center of the Flight Deck, unless, as in the French Aircraft Carrier *Bearn* (1922-1968), Flight Deck closures are provided.

• When the elevator is raised, there is an opening in the Hangar Deck unless an elevator pit platform is installed.

• The elevator trunk requires a large piece of prime real estate in the center of the Gallery Deck.

• In a carrier with a ballistic Flight Deck, the hangar is unprotected except when the elevator is full up.

• The hangar can become a large pit filled with explosive gases as it did in the *USS Princeton* (CVL-23) during World War II. *Princeton's* aircraft elevators were blown ajar by the explosion of gasoline vapor in the hangar.

• Flaming debris or other hazardous material can not be conveniently and as rapidly jettisoned over the side from the hangar unless a separate large access is provided.

• Adequate operating and handling area for replenishment-at-sea is much more difficult to obtain.

• In port, craning of aircraft from the dock would have to be to the Flight Deck rather than to the Hangar Deck.

• Fuel spillage into the elevator trunk can produce hazardous conditions within the ship.

Flight Decks with deck edge aircraft elevators and no inboard aircraft elevators were first incorporated in the design of the *USS United States* (CVB-58) which was not constructed (keel laid 18 April 1949 — construction halted 23 April 1949). *USS Forrestal*, commissioned 1 October 1955, was the first American Carrier to be constructed with deck edge elevators only. Advantages which may be cited for deck edge elevators are:

• Ability to accommodate larger aircraft (tails may be hung over the side as long as main landing gear and nose fit on platform).

• In both Flight and Hangar Deck positions the elevator platform is adjacent to, rather than in, the center of traffic patterns.

• Main Deck is more accessible for replenishment-at-sea.

• Hangar Deck can be ventilated more easily.

• Hazardous material can be quickly jettisoned from the hangar.

• Aircraft and ship's boats can be craned from the dock to the Hangar Deck.

• Jet aircraft can be delivered to main (hangar) deck with engines on and "hot taxied" into the hangar.

• Damage to an elevator not in full up position will not normally foul the Flight Deck.

• Platform location is more easily moved if required as in the case of Ship Alterations (SHIPALTS) developed to accommodate JBDs for the F-14A.

Disadvantages which may be cited for deck edge aircraft elevators are:

• Sea spray impingement on aircraft hastens corrosion.

• Green water on platform in the lowered position is a danger to aircraft and personnel.

• Elevator platforms have been lifted by wave action and allowed to slam.

• Limited freeboard of smaller ships makes platform more susceptible to wave damage.

• To provide adequate freeboard for aircraft elevators the ship may have to be made deeper with a concomitant increase in displacement, power, et cetera.

• Possibility of Main Deck (hangar) flooding during high Sea States. For example, CVA-42 (*F.D.R.*) took a wave through the hangar doorway to her No. 1 aircraft elevator during 1974 which resulted in a flooded hangar, aircraft damaged by the hangar door, and death to a crewman caught between the sprung door and an aircraft.

Ideally, aircraft elevators would be supplied in sufficient quantity and be so located that all phases of

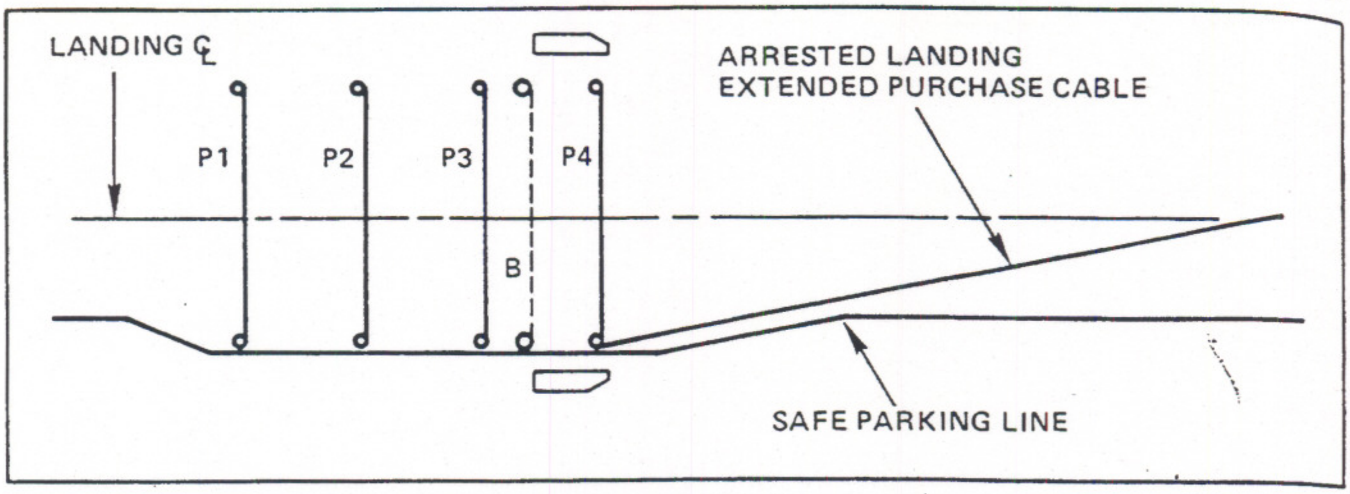


Figure 5. Safe Parking Line.

air operations would be supported without delay. During recovery of aircraft at least one elevator should be available to "hot taxi" an aircraft known to be in down status upon landing. During launching of aircraft sufficient elevator capacity must be available to "cycle" aircraft to the Flight Deck to support an Alpha Strike, i.e., all aircraft which are in an "up" condition are launched as rapidly as possible and are "cycled" continuously for an all out effort. Between operational "cycles" the elevators will be required to "cycle" respotted aircraft between Flight and Hangar Decks. Each platform must be of sufficient size to safely handle the largest aircraft expected on board. It should also be configured, if possible, to carry two or three smaller aircraft simultaneously. When carrying aircraft, the platform and machinery should be capable of lifting aviation ordnance on Dollies in addition to the aircraft and their tractors. Consideration must also be given to elevator separation and the number of elevators to increase the availability of elevators after battle damage.

A problem of considerable magnitude with deck edge aircraft elevators is their exposure to sea spray and sea water. Ship freeboard and length mainly determine the proximity of the elevator to salt spray and green water. Sponson and elevator platform design determine the seriousness of the problem. Even on such a large ship as the *Nimitz* there is sufficient likelihood of a problem occurring, and so the elevator machinery was designed to remove slack from the cable automatically should a wave lift the platform.

Safe Parking Areas

Safe parking is usually defined as the Flight Deck area clear of the landing area; this includes space on both the port and starboard side of the landing lane.

For design purposes safe parking is defined as that area at least 50 feet to starboard of the landing area centerline in which no contact can occur between the aircraft being recovered, the barricade, the cross deck pendant or the Purchase Cable and aircraft, yellow

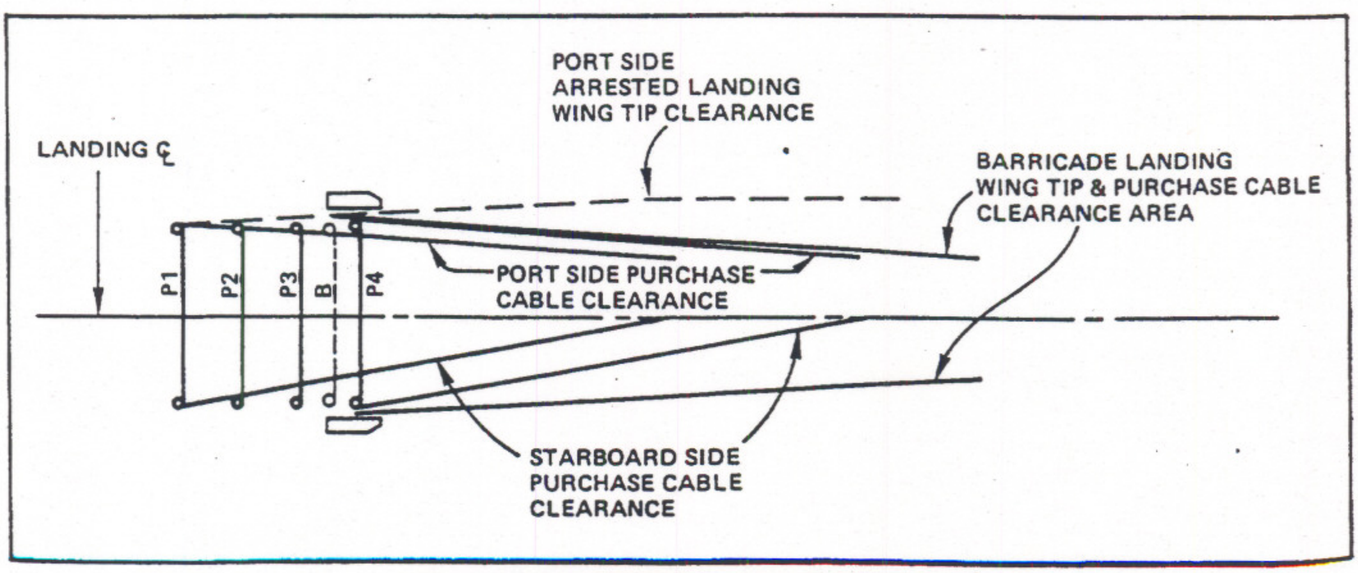


Figure 6. Theoretical Safe Parking Requirement.

gear, or personnel starboard of the landing area. The safe parking line is drawn 50 feet to starboard of the landing centerline from the forward ramp aft toward the arresting area, then slightly more to starboard to skirt the arresting gear sheaves and return to the 50-foot width aft of the sheaves (See Figure 5). Figure 6 is an example of safe parking requirements on an arbitrary but practical basis. The starboard safe parking line is located such that there is a clear deck 50 feet to starboard of the landing centerline between the after ramp and P1. From P1 to the barricade stanchion the line should be starboard of the deck sheaves. From the stanchion forward it must clear the barricade Purchase Cable and aircraft wing tip path. For the port side, the same criteria applies except that the requirement for arrested landing wing-tip clearance is *greater* than the starboard clearance. This is due to allowance for either an axial landing (in relation to the recovery area centerline) 20 feet to port of the recovery area centerline, or a landing with the aircraft yawed 7° to port of the recovery area centerline with touchdown on the recovery area centerline.

Aircraft Services

Aircraft services include: Electrical, Fuel, Starting Air, Air Conditioning, Oxygen (liquid and gaseous), Nitrogen, and Inertial Navigation System Alignment. Of these, all except oxygen (both liquid and gaseous) because of the safety problem, may be built into service outlets in the deck. Liquid and gaseous oxygen are distributed to the aircraft by mobile carts. Therefore, only one O_2/N_2 Filling Station is required, and this station should be conveniently located adjacent to the hangar area.

To determine the location of the various aircraft services, spotting studies are conducted for all notional airwings, flight deck configurations, and variations in operational modes to determine the optimum number of service outlets and their locations.

Weapons Services

Weapons Services consist of the weapons elevators, Dollies, hoists, and miscellaneous gear necessary for arming the aircraft. All of these are mobile except for the weapons elevators which should be kept out of the landing area entirely and out of traffic patterns as much as possible. The weapons elevators, with their ballistic hatches opening above the deck, present a Flight Deck traffic problem. The design and location of weapons elevators should minimize the possibility of precipitation and fuel spills draining into the elevator shafts. Inboard elevators should be placed just inboard or outboard of the hangar side bulkhead. For two stage elevators with transfer on the Hangar Deck level, the outboard position has the advantage of not interfering with hangar functions.

Deck edge weapons elevators, as on MIDWAY Class ships, have the advantages of being outside the Flight Deck traffic flow and do not interfere with hangar functions, but they are subject to the same salt water problems as the deck edge aircraft elevators unless enclosed within the sponson. There are several advantages for outboard weapons elevators which should be considered. They are:

- Increased ship safety and decreased ship vulnerability.
- No interference with aircraft movement.
- Increased "strikeup" rates.
- Use less valuable Flight Deck real estate.
- Could also provide elevator service in sponson areas to vital aircraft/weapon support equipments located between the Hangar and Flight Decks, thereby freeing Hangar/Flight Decks of this type gear.

Self-Defense Systems

Self-Defense Systems affect Flight Deck design by the extent of protection required, weapon requirements, and the threat to be defeated. The arcs of fire of the Self-Defense Systems are generally specified as providing 360° hemispherical coverage. Commencing with the CVA-59 design, all Self-Defense Systems, with the exception of gun/missile directors, have been installed below the Flight Deck level. To provide 360° surface coverage, *four* systems, one in each quadrant, are required. Each system has been installed on a weapons sponson. To provide hemispherical coverage the weapon sponson must be located in relation to the Flight Deck so that the weapon has at least 90° azimuth coverage plus sufficient elevation to cover targets directly overhead to slightly below the horizon, including an allowance for roll and pitch.

To allow for maximum possible quadrant coverage, these weapon sponsons have generally been located at the forward and after ends of the Flight Deck sponsons. There have been seakeeping problems with the forward weapon sponsons due to their proximity to the bow.

The after weapons sponsons do not generally suffer bad weather damage due to their protected location aft and inboard of the Flight Deck sponsons. However, the requirements of the after weapons sponsons dictate somewhat the shape of the Flight Deck in this area.

Eliminating the forward weapons and supporting sponsons makes the design of the after weapon sponsons and the adjacent Flight Deck area more difficult since the after weapons must now provide as much forward fire as possible.

The Naval Air Systems Command requires clearance above a *negative* 15° angle drawn outboard and perpendicular to the Flight Deck edge to prevent aircraft contact with ship subsystems, for example, whip antennas.

Fire and NBC Protection

All Flight Decks must be provided with a deck edge plus inboard sprinkler system capable of covering the entire deck for both fire protection and NBC (Nuclear, Biological, Chemical) washdown. Facilities for fire hoses must also be provided for total Flight Deck coverage, including overlap. Weapon jettisoning ramps must be provided to enable personnel to remove "hot" weapons from the Flight Deck without striking any part of the ship on the way to the sea.

Accesses

Access to the Flight Deck is required by large numbers of personnel for many reasons and for a variety of tasks.

Catapult associated personnel include the Catapult Officer, Deck Edge Station Operator and all those associated with attaching the aircraft to the catapult, removing the weapon safety pins, checking aircraft launch weight, et cetera. These personnel must have immediate and unimpeded access from the Gallery Deck to the catapult areas via Gallery Deck catwalks.

Arresting gear personnel include the LSO (Landing Signal Officer), his assistant, the Arresting Gear Deck Edge Station Operators, the Hookman, and the Aircraft Directors. Their access requirements are similar to those of the catapult personnel except that in an emergency, a ramp strike for example, the LSO and the Station Operators will require escape chutes to a haven below the Flight Deck.

The Flight Deck Officer and his team require unimpeded access to the Flight Deck from Flight Deck Control in the Island structure.

Squadron maintenance personnel are generally located in Gallery Deck compartments outboard of the sheer strake and require access to recovered aircraft via Gallery Deck catwalks. Access must be provided which allows safe transport of tools and personnel.

Aircraft fueling teams must have access between the Gallery Deck and Flight Deck adjacent to their fueling stations.

Weapons elevator operators and handling personnel are not allowed to ride the weapons elevators and must, therefore, have access to the Flight Deck via catwalks.

Missile wing and fin stowages must be located near aircraft parking areas and have direct access to the starboard Gallery Deck catwalk and the Flight Deck. Inboard stowages are not acceptable due to the weight, size, and fragile nature of these aerodynamic surfaces which might be damaged by passage through hatchways and doors. Parachute flare ready service lockers, also located at the Gallery Deck edge, must have clear drop zones to the water in the event jettisoning is required.

Aircrew Ready Rooms are usually distributed on the Gallery Deck. Aircrews usually are provided with Ready Rooms sufficiently forward or aft to allow direct access to the catwalks from the main fore and aft passageways.

Flight Deck Design

Flight Deck Design is the integration of the functions previously described. However, before the Flight Deck components can be arranged as a functional system, other factors related to both "ship" and "aviation" functions must be considered. These include:

- Approximate Hull Length.
- Approximate Beam.
- Approximate Hull Shape.
- Machinery Plant Candidate(s).
- Armor Box Volume and Height.
- Number of Shafts.
- Approximate Hangar Area and Height.
- Freeboard to Main and Flight Decks.

Prior to laying out the Flight Deck, an inboard profile of the ship locating the machinery plant, aviation ordnance magazines, and the aircraft hangar as dedicated blocks of space is developed.

Inboard Profile

Some possible configurations of the magazine-machinery complex are shown in Figure 7. Hangar Deck arrangement is the result of many compromises to optimize as much as possible each of its operational requirements. The Flight Deck dictates location of the upper stage weapons elevator along or outboard of the starboard hangar side bulkhead. Weapon elevator hatches should not be within the landing area on the Flight Deck. The lower stage elevator locations are dictated by magazine constraints. Weapons elevator locations in a hangar bay as illustrated by Figure 8 represent an acceptable compromise from the aircraft

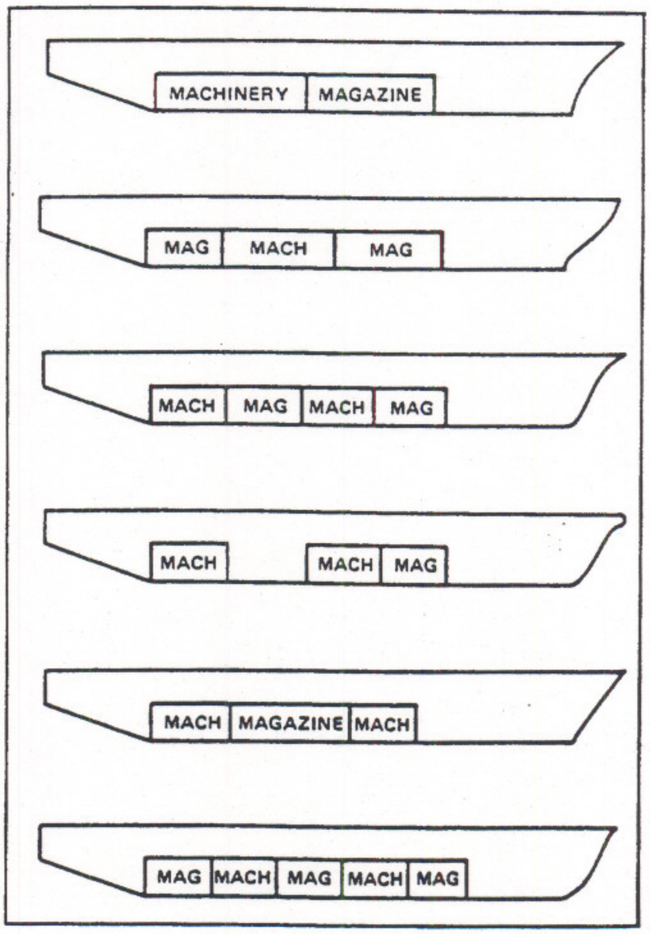


Figure 7. Machinery/Magazine Arrangements.

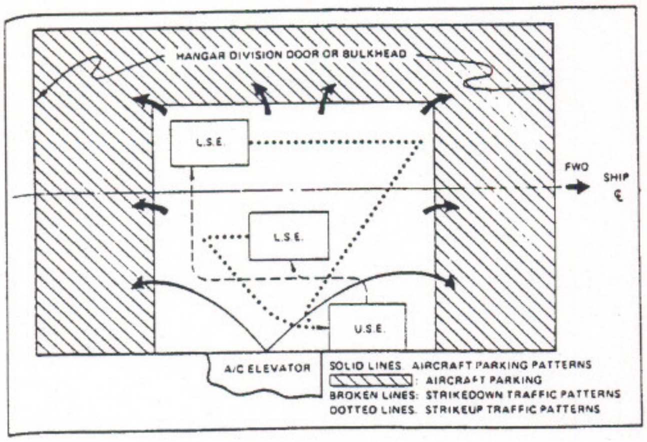


Figure 8. Example of a Hangar Bay Arrangement.

handling, aircraft parking, and weapons "strikeup/strikedown" point of view.

Integration of Launch and Recovery Area

Of primary concern is the relationship of the aircraft recovery and launching areas. Previously the functional and physical relationship were examined as separate entities, now the two must be combined. The latest criteria for Aircraft Carriers are that a recovery "Bolter" will not pass through the recovery parking area and the aircraft recovery and launch may occur simultaneously. Thus, the recovery and launch blocks fit together as illustrated by Figure 9. It is obvious that changes in the launch recovery interface requirements will change the size and shape of the blocks as well as their angular relationship. Alpha is limited to a maximum value of 12°.

These are several factors which may constrain the minimum value of Alpha. These factors are:

- "Bolter" (previously described).
- Simultaneous Launch and Recovery: Alpha must be sufficiently large to allow the largest aircraft to be attached to a catapult while standing clear of the recovery area safe parking line.
- Safe Parking: Provision is usually made to starboard of the recovery area for "safe parking", i.e., away from "Bolters." This may be accomplished by angling the recovery area or by offsetting to port an axial recovery area.

The requirements for launch and recovery must be reconciled with each other and with the postulated hull before the remaining functions are considered. The recovery area has a minimum length and width determined by the postulated Air Wing and ship speed. The length of the recovery area may be increased should ship length permit it. A rule of thumb is that the forward recovery ramp should be about 30% of LBP back from the forward edge of the Flight Deck in order to preclude damage to the sponson from wave action in a high sea state.

A second rule of thumb is that the after end of the Flight Deck sponsons will terminate no further aft than 15% of LBP from the AP. This rule of thumb is associated with a requirement to avoid damage during high Sea State condition. However, there are no known instances of Aircraft Carriers receiving either Flight Deck or weapon sponson damage in this area, nor is there any evidence of transom damage due to following seas.

The starboard sponsons support the Island and a majority of the aircraft elevators. The extent and location of the starboard sponson is also dictated by aircraft elevator locations in relation to the hangar bays and by alignment of replenishment stations with the replenishment stations of the various Auxiliary Ships.

The Island must be located on a starboard sponson among the aircraft elevators, and provide for a suitable run of uptakes and ventilation ducts for the machinery spaces for a fossil fuel powered ship. Idealized placement of the Island and the aircraft elevators will probably not be possible and a series of compromises will be made. In addition to the criteria for aircraft elevator locations which are driven by alignment with other than aircraft related functions and survivability requirements, these aircraft Flight Deck constraints should also be applied:

- An aircraft elevator should be immediately aft of the JBD Catapult No. 1 on the starboard side.
- An aircraft elevator should be to starboard of the full "runout" point of the recovery area to allow "hot taxiing" of "down" aircraft onto the elevator and into the hangar.
- At least one aircraft elevator should service each hangar bay.
- There should be *no* blind access hangar bays, i.e., each bay should be serviced by at least one aircraft elevator and have access to another bay through hangar division doors, or be serviced by two aircraft elevators.
- A port side aircraft elevator provides grater mission survivability in addition to providing "strikedown" capability for VERTREP of stores during alongside replenishment operations.

These requirements would all be met in an ideal situation, but the objective is to accomplish as many as possible within each design's constraints. The primary objective is to provide unimpeded traffic flow to other catapults and from the recovery area. Consideration

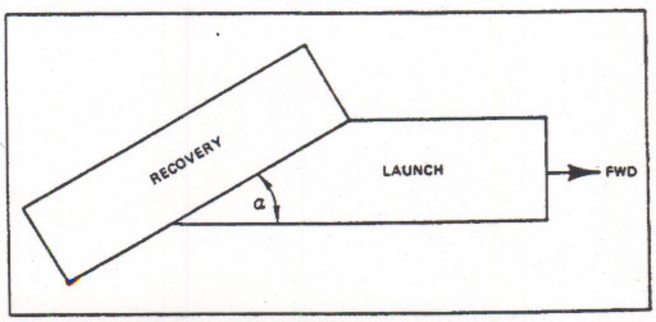


Figure 9. Launch/Recovery Interface.

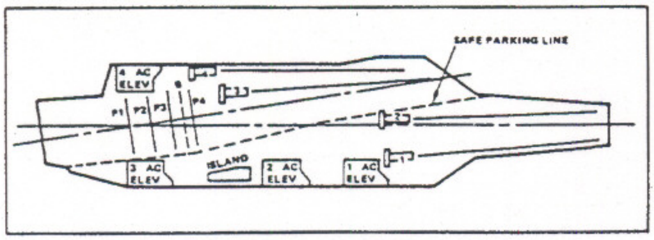


Figure 10. Typical Flight Deck.

must also be given to delivery routes for aviation ordnance as well as routes between the shops and the aircraft.

Flight Deck Integration

Figure 10 illustrates a typical Flight Deck arrangement that conforms to the guidelines discussed previously. Note that the after ramp of the recovery area has been angled in alignment with the recovery area, and that the forward end of the port sponson has an extension to accommodate maximum offset recoveries. The bow catapults have been placed essentially parallel to each other. The waist catapults are placed outboard of the sheer strake to prevent penetration of the sheer strake by the catapult troughs. No. 4 Catapult is parallel to, and as close to, the port deck edge as possible, and is set back as far as possible to preclude interference between its JBD and the port side barricade stanchion while allowing No. 3 Catapult to have its JBD forward and clear of aircraft on Station Zero of No. 4 Catapult. No. 3 Catapult is angled to port and is set forward on the port sponson to eliminate interference, as much as possible, with aircraft at Station Zero of No. 4 Catapult and to preclude slamming of the deck pendant/Purchase Cable connection for P4 on the JBD aluminum panels.

Number 1 aircraft elevator is just aft of the JBD for Number 1 Catapult. Provision should be made for immediate removal of an aircraft which "goes down on launch" to an area away from the launch area without interfering with aircraft awaiting launch. The Flight Deck illustrated by Figure 10 provides this capability as follows:

- Catapult No. 1 and 2: Removal is to the starboard sponson and aircraft elevator No. 1.
- Catapult No. 3: Removal is to starboard adjacent or aft of the Island.
- Catapult No. 4: Removal is the same as for Catapult No. 3 except that Catapult No. 3 must be cleared first.

Number Three aircraft elevator is sufficiently forward to just clear the safe parking line. Number Two elevator and the Island are located to allow Number Two elevator to service the center hangar bay and to allow the intakes and uptakes easy access to the Island.

Figure 10 represents the latest design in the evolution of aircraft carrier Flight Deck arrangements, yet it has the following limitations and undesirable features:

- Closeness of the aft elevators and the arresting gear hampers arresting gear machinery arrangement.
- Arresting area size is restricted by proximity of the aft elevators.
- Port side extension at forward end of recovery area hampers maintenance operations in some port facilities.
- Proximity of Number One elevator and Number One catapult could hamper aircraft operations.

These disadvantages might limit the development of future aircraft since modification of the Flight Deck would be precluded by the excessive cost.

Conclusions

This paper was written to examine the parameters which affect Aircraft Carrier design from the aviation point of view, and to document the "rules-of-thumb," which have been and are being used, but not to delineate a specific methodology for design.

Each ship design requires a new and different approach to achieve a design solution even though the solution may be evolutionary rather than revolutionary.