HERBERT A. MEIER & PETER A. GALE

ALTERNATIVES IN AIRCRAFT CARRIER DESIGN

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THE AUTHORS

Mr. Herbert A. Meier *graduated from the University of Michigan in 1951, receiving his BS degree in Naval Architecture and Marine Engineering. He was employed from 1951 to 1975 by the U.S. Navy in the Ship Design Division, Naval Ship Engineering Center and its predecessor, Bureau of Ships. During this period, he was Project Naval Architect for preliminary design of the DLG(N) 35, PG 84, CVA(N) 67 [a design made in parallel with the design of CVA-67], AKA 113, MSO 523 [not built], CVA(N) 68, and ASR 21 Classes. He also served in other capacities, and for several years was Head, Advanced Concepts Section, Preliminary Design Branch; served on the OPNAV Study Group formulating the characteristics for the Sea Control Ship; studied various applications of the catamaran concept; and led the Group that developed numerous studies on Aircraft Carrier Alternatives as part of the CVAN 71 Class Concept Formulation effort at NAVSEC in the early 1970's. Currently, he is employed as a Consultant to the Navy on a Comparative Naval Architectural Program involving the analysis of design characteristics of foreign surface combatant ships and comparison of the foreign technical design approach with that of equivalent U.S. Navy approaches. A member of A.S.N.E. since 1976, he is also a member of S.N.A.M.E.*

Mr. Peter A. Gale *received his BS degree in Naval Architecture and Marine Engineering from Webb Institute of Naval Architecture in 1959 and his MS degree in Nautical Engineering from Stevens Institute in 1964, having attended the latter on a S.N.A.M.E. Graduate Scholarship. His entire professional career has been spent in the Ship Design Division of the Bureau of Ships, and more recently, that of the Naval Ship Engineering Center. He has participated in the development of numerous surface ship designs including destroyers, minesweepers, salvage and rescue tugs, amphibious force ships, and auxiliaries. For several years he was Head, Hydrodynamics Section in the Advanced Technology Branch, but for the past four and one-half years he has been concerned almost exclusively with the design of aircraft carriers and smaller air-capable ships; two years as a principal in the Sea Control Ship design effort at NAVSEC, and two and one-half years as a participant in the Navy's studies of VSTOL Support Ship and Aircraft Carrier Alternatives. Recently, he served as the NAVSEC Representative on the Navy's CVNX Characteristics Study Group established by the Chief of Naval Operations. A member of A.S.N.E. since 1976 and the recipient of the Jimmie Hamilton Award for 1975 for the best paper published in the Journal, he is also a member of the Royal Institution of Naval Architects and S.N.A.M.E., presently serving on the latter's Committee on the Journal of Ship Research.*

INTRODUCTION

The design of any warship can be thought of in terms of packaging certain weapons and sensors, defined as payload, in a ship which has specific mobile platform performance characteristics such that this payload can be utilized with maximum effectiveness consistent with cost, tactical requirements, and any other requirements or constraints that may be laid down by the platform sponsor. The design of an aircraft carrier, however, is a *unique* design problem because its aircraft, its primary military payload, are in themselves mobile payload platforms which use the ship as an operational and support base. The aircraft carrier's unique payload imposes numerous requirements and constraints which make the design one of the most interesting and challenging assignments for a naval architect. This paper explores some of the design alternatives available to the aircraft carrier designer and how some of these alternatives have been or might be resolved in the "trade-off" process during a design effort.

It is well to recognize at the outset that there is *no* perfect design for an aircraft carrier which can be arrived at merely by stint of superior engineering. The performance of those ships depends heavily on how closely the role initially envisioned for them fits their ultimate task and how realistic the constraints put on the design actually prove to be. If past history is any precursor, one may well despair that, in many respects, the better the naval architect does his job of optimizing a new design to suit established requirements and constraints, the less optimum the ship will ultimately prove to be. It is often the case that a ship whose design is carefully tailored to suit a particular set of requirements is relatively inflexible in the face of changing requirements. One has only to compare the actual roles of battleships, cruisers, destroyers and a host of auxiliaries in World War II to the roles envisioned for them at the time they were designed to prove this point. Fortunately, the aircraft carrier, by the very nature of its payload and configuration, is perhaps the most adaptable of all naval ship types to changing roles.

Philosophy aside, once the need for a new aircraft carrier has been identified, the designer has to concentrate on the real issues: *size, configuration* and *subsystem features.* The first two of these *three* broad categories are discussed in this paper. Due to space constraints, the third is not.

SIZE

Hypothetically, given a certain number of aircraft to be based on mobile platforms at sea, the optimum from a "least ship cost per embarked aircraft" standpoint is simply a single ship as large as is necessary for all the NAVY's sea-based aircraft, even if it is a million ton ship, 2,500 feet long. In other words, "ship cost per embarked aircraft" *decreases* as unit size increases. While this trend may not actually continue to the extreme, studies have shown it to be true over a size range greater than that of practical interest.

Before discussing the primary reasons for this economy of size phenomenon, the dominant factors which influence carrier size must be briefly summarized:

1) FLIGHT DECK OPERATIONAL CONCEPT

The operational concept for the flight deck can have a very significant influence on its arrangement and its required size. There is, of course, a strong correlation between flight deck size and carrier size. This is discussed later in the paper. By the phrase "operational concept" reference is made to aspects such as the following:

a) The assumed maximum tempo of aircraft launches and recoveries, and hence, the required ordnance strike-up and handling rates, refueling rates and catapult cycle times; the required numbers of catapults and aircraft elevators; the requirements governing the positions of aircraft elevators relative to launch and recovery areas (Must be well clear or not?); and the need for a flight deck arrangement which facilitates the flow of traffic on the deck, thereby enabling aircraft to be cleared rapidly from the recovery area during a rapid recovery sequence or moved rapidly to the catapults in a rapid launch sequence.

b) The number of simultaneous missions that must be executed, and hence, the variety of aircraft and ordnance types required to be handled on board essentially in parallel.

c) The need for the carrier to be able to launch one or more defensive aircraft on literally a moment's notice in the midst of an extended aircraft recovery operation, and hence, the need for one or more catapults to be located clear of the recovery area.

By way of illustration, recent U.S. NAVY carriers are designed for multi-mission, high-tempo flight operations and two catapults are located clear of the recovery area for the launch of defensive aircraft on short notice. Four catapults and four aircraft elevators are provided; and some of the elevators can be used during launch and recovery flight operations. At the other extreme would be a carrier designed for low-tempo, single mission operations with *no* requirement that a free catapult be available to launch an aircraft on short notice during aircraft recoveries, and *no* requirement that an aircraft elevator be free for use during aircraft recoveries. In this extreme case, a flight deck featuring an axial recovery area with the few required aircraft elevators and catapults located within the recovery area boundaries would be permissable.

2) AIRCRAFT TYPES TO BE OPERATED AND SUPPORTED

The aircraft types to be *operated* influence the required sizes of launch and recovery areas as well as elevator platforms, the minimum required clear hangar height, the required deck strength in recovery and parking areas, and the minimum acceptable spacing between adjacent catapults. The *number* of aircraft types to be *supported* strongly influences the required sizes of the aviation maintenance facilities and storerooms to be provided.

3) AIR WING SIZE

The total aircraft parking area to be provided on a new carrier, i.e., the hangar area *plus* flight deck safe parking area, must be adequate to accommodate the entire specified Air Wing, i.e., the total number of aircraft in a specified "mix" of aircraft types, in a realistic operational parking configuration or "spot." The Air Wing size also determines the required Air Wing manning which in turn affects the size of the ship's human support facilities, both directly and indirectly, since a substantial fraction of the Ship's Company supports the Air Wing and is sized in proportion to the Air Wing manning. Aircraft maintenance facilities and storeroom sizes are also affected by Air Wing size.

4) MAGAZINE CAPACITY

All aircraft carriers contain large magazines for the stowage of aviation ordnance. These magazines consist of a number of bays, individually rather large, which are centrally located low in the ship and are surrounded by protective armor. Thus, magazine capacity can have a significant effect on hull weight and even size. If magazine capacity is increased to an extent where hull size is affected, the added hull weight is partially due to the hull size increase and partially due to the necessary increase in the extent of the protective features provided. It is important to note that magazine space rather than the weight of stowed ordnance is the important factor. Thus, the advent of new, lighter weapons which require more stowage space does not suggest that magazine *capacities* and, hence, hull *size* can be significantly reduced in the future.

5) PROPULSION PLANT

A carrier's propulsion plant utilizes a large block of space low in the ship and is also surrounded by a protective envelope. Thus, the propulsion plant has a dominant effect on carrier size for the same reason as magazine capacity. The size of the machinery box on a carrier is a function of the plant horsepower rating and the number of propulsion shafts which, in turn, are determined by speed requirements both when catapulting and when not catapulting. In addition, shaft alleys require significant amounts of space as do air intake and exhaust ducts.

6) Passive Protection Features

A number of passive protection features are reflected in modern carriers that are designed to provide protection against weapons threats which strike the hull or which detonate away from the hull, above or below the waterline. Some of these features add substantial amounts of structural weight to the ship but do not require additional space. Others consume space and, hence, also increase hull size and add weight which is hull size dependent.

Turning now to the reasons for the economy of size in an aircraft carrier, one of the most important stems from the fact that it is easier, in terms of installed horsepower per ton of displacement, to drive a large ship in the 30 plus knot speed range than a smaller one. This is illustrated by the fact that, for nearly equal speeds, a destroyer requires approximately 11 SHP/ton as compared to about 3.5 SHP/ton for CV's of the *Forrestal* to *Nimitz* type. This point is further illustrated in Figure 1, which is a plot of the relationship between speed, displacement, length and prismatic coefficient for a ship with a specific installed horsepower and a constant maximum section. The maximum section corresponds to the current limits imposed by construction facilities and navigational restrictions. From this plot, it can be seen that for increased lengths up to at least 1,200 feet, and correspondingly proportionate increases in displacement, there is *no* sacrifice in speed. For example, it requires about the *same* horsepower to propel a 61,000 ton, 720 foot long hull at a typical maximum speed as it does to propel a 110,000 ton hull, slightly over 1,200 feet long, at the same speed. Certainly a 2,500 foot long ship and probably even a 1,200 foot ship are unacceptable both tactically and from a vulnerability and facilities standpoint. However, the point is clearly demonstrated by this example.

Another major factor contributing to the economy of size is related to the so-called "Square-Cube Law," i.e., the volume of a container increases by the *cube* of the ratio of any uniform dimensional changes while its surface area increases by the *square* of the same ratio. About 50 percent of the total weight of a modern carrier is devoted to structure, and a substantial portion of this structural weight is devoted to enclosing the hull, i.e., it is proportional to the hull's surface area. Thus, due to the "Square-Cube Law," as a carrier's hull is increased in size, for example to accommodate a larger Air Wing, the useful internal hull volume increases at a greater rate than does the hull structural weight.

This effect is magnified in the case of magazines which are heavily protected. Large aircraft carriers are valuable assets that are required to carry several thousand tons of aircraft ordnance which is vulnerable to mass detonation by incoming weapons. It has always been past practice to protect this ammunition, and to a lesser extent, propulsion machinery and certain other vital spaces by arranging them contiguously within a so-called "armored-box". Protection of the "armored box," or citadel, requires considerable weight and volume. Because of the "Square-Cube Law," it is apparent that large economies in the ratio of protection investment to protected volume are inherent in large ships. However, it must be realized that this argument for a large ship is valid only to the extent that the type

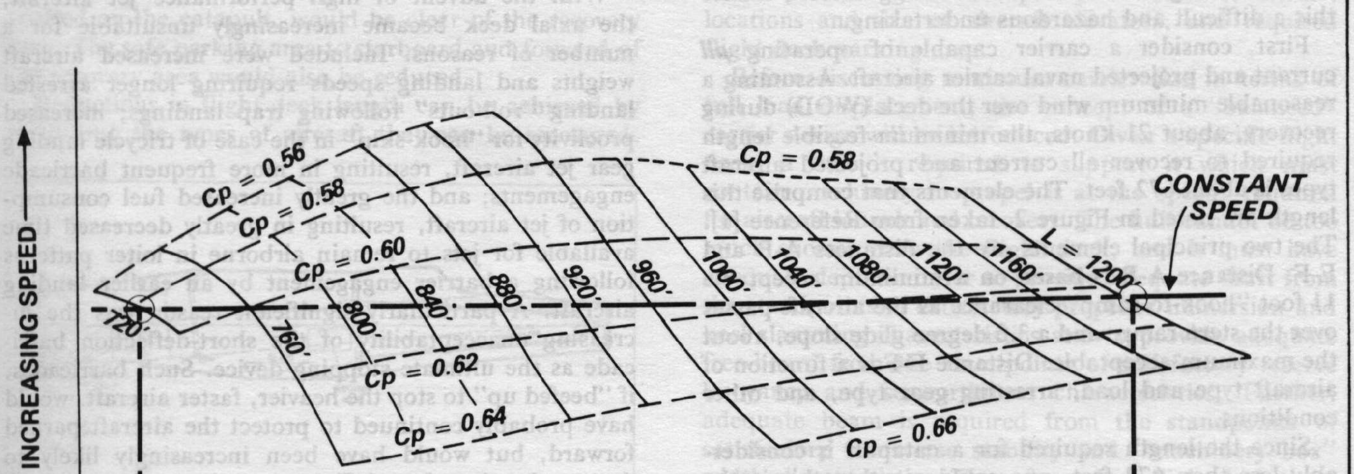


Figure 1. SPEED versus DISPLACEMENT, LENGTH and PRISMATIC COEFFICIENT for a Specific Constant Power.

of protection can be achieved that is required to assure virtually that mass detonation of ordnance will not occur.

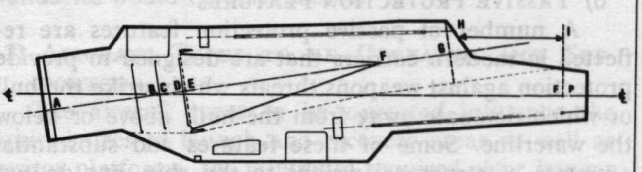
In attempting to capitalize on the economics inherent in large carrier size, one obviously has to consider the constraints imposed by harbors and by construction and repair facilities. Harbor restrictions now and in the foreseeable future dictate a maximum draft of about 38 feet, but impose no further dimensional restrictions with the possible exception of certain bridge clearances. Construction facility restrictions currently impose a maximum hull beam on the waterline of 135 feet, a maximum length on the waterline of 1,080 feet, and a maximum beam at the flight deck of 252 feet. The flight deck width restriction is due to the location of crane rails relative to the graving dock in which the ships are built, and this is circumvented at the forward end of the port sponson on our large carriers by installing semi-portable flight deck extensions at this point. Obviously, current construction facility restrictions could be circumvented by building new and larger facilities.

So far, the economies of large carrier size and certain constraints on that size have been discussed. A more frequent issue in the current environment concerns the *minimum* feasible carrier size. In this case the answer is not nearly as easy as a recital of the constraints imposed by the largest available building dock. Indeed there are a considerable number of minima depending primarily upon the dominant sizing factors previously mentioned. Also, there is no generally accepted single indicator of carrier size; the *two* indicators most frequently referred to are flight deck length and full load displacement.

An attempt is made in the following paragraphs to discuss briefly the question of minimum carrier size with some heavily caveated numerical examples. The extremely large number of influencing factors makes this a difficult and hazardous undertaking.

First, consider a carrier capable of operating *all* current and projected naval carrier aircraft. Assuming a reasonable minimum wind over the deck (WOD) during recovery, about 21 knots, the minimum feasible length required to recover all current and projected aircraft types is about 672 feet. The elements that comprise this length are noted in Figure 2, taken from Reference [1]. The two principal elements are the distances A-B and E-F. Distance A-B is based on a minimum acceptable 11 foot "hook-to-ramp" clearance as the aircraft passes over the stern ramp, and a 3.5 degree glide slope, about the maximum acceptable. Distance E-F is a function of aircraft type and load, arresting gear type, and other conditions.

RECOVERY AREA ELEMENTS:	DISTANCE (FEET)
A-B: RAMP TO HOOK TOUCHDOWN POINT (HTDP)	180
B-C: HTDP TO 2nd WIRE	3 (MINIMUM)
C-D: WIRE SPACING	40
D-E: 3rd WIRE TO BARRICADE	5
E-F: WIRE RUNOUT	350
F-G: BARRICADE STRETCH AND TURNAROUND	94
RECOVERY AREA LENGTH =	672



MINIMUM ANGLED DECK CONFIGURATION I

- FOR ALL CURRENT AND PROJECTED AIRCRAFT
- WITH ONE CATAPULT CLEAR RECOVERY AREA
- 21 KNOTS MINIMUM WIND-OVER-DECK DURING RECOVERY

Figure 2.

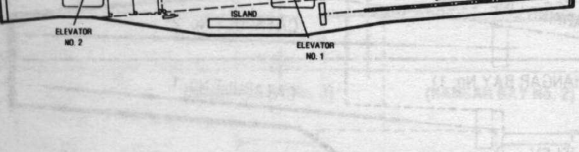
Since the length required for a catapult is considerably less than 672 feet, one could say that this is the *minimum* length flight deck that could alternately land and launch all modern aircraft. However, in this arrangement there obviously would be no parking area forward for aircraft, and hence, before a second aircraft could land, a time consuming evolution of either "striking" the just-landed aircraft below, or moving it to small sponsons aft, would have to be used. This is obviously an unacceptable solution for any carrier which is performing high tempo air operations with multiple aircraft missions. Also, somewhat more length would be required, in any case, since the width of the minimum recovery area is too great to be acceptable at the leading edge of the flight deck of such a small carrier, due to green water slamming impact considerations. Thus, a tapered region would have to be placed forward of the minimum recovery area in order to reduce the width of the leading edge of the flight deck. In World War II era U.S. carriers, this type of flight deck, called an *axial deck,* was made acceptable by adding a parking area forward of the landing area. This was in the era of piston-engined aircraft when the pilot of a landing aircraft cut his engine power at the ramp when directed by the landing signal officer, and either made a successful trap landing or engaged the barricade located to protect the aircraft parked forward of the recovery area.

With the advent of high performance jet aircraft, the axial deck became increasingly unsuitable for a number of reasons. Included were increased aircraft weights and landing speeds requiring longer arrested landing "roll-outs" following trap landings; increased proclivity for "hook-skip" in the case of tricycle landing gear jet aircraft, resulting in more frequent barricade engagements; and the greatly increased fuel consumption of jet aircraft, resulting in greatly decreased time available for jets to remain airborne in loiter patterns following a barrier engagement by an earlier landing aircraft. A particularly significant reason was the increasing unacceptability of the short-deflection barricade as the ultimate stopping device. Such barricades, if "beefed up" to stop the heavier, faster aircraft, would have probably continued to protect the aircraft parked forward, but would have been increasingly likely to destroy the aircraft and flight crews impacting them. A long-runout barricade, if permanently rigged during aircraft recoveries in the traditional position at the upwind end of the recovery area, would require most of the remainder of the flight deck forward of the barricade to be clear of parked aircraft, and even then this would *not* insure that there would not be some damage to the aircraft impacting the barricade.

To solve these problems, the "angled deck" configuration was developed. This flight deck arrangement allows the pilot to apply maximum thrust and to execute a "touch-and-go" when a trap landing is not achieved, i.e., when a "bolter" has occurred. The deck configuration at the same time retains a safe parking area forward to which aircraft can be quickly moved after recovery to clear the landing area for the next aircraft. An angled flight deck is shown in Figure 2.

The minimum configuration shown in Figure 2 has a flight deck length of 912 feet. This resulted from the additional requirement that the catapult on the starboard side should be able to have a plane spotted on it for take-off without infringing on the recovery area. This is often referred to as a "simultaneous launch and recovery capability." This requirement in turn necessitated a rather high angle on the angled deck, 8.5 degrees, and a large overhanging port sponson. Because of potential sponson slamming, transverse weight balance, and structural considerations, there are limits on how far outboard and forward such a sponson can be permitted to extend. In this case, sponson slamming considerations were governing, and the distance H-I was set at 21 percent of the hull waterline length in order to keep the risk of sponson structural damage resulting from sponson slamming at a reasonable level. Consequently, a flight deck length of 912 feet resulted. Clearly, the need to prevent excessive sea impacts on the underside of the port sponson forward can significantly affect flight deck length for an "angled deck" configuration. The length of this angled flight deck could be reduced slightly if the angle of the landing path, and hence, the outboard overhang of the port sponson, was reduced thereby permitting the forward edge of the sponson to be closer to the bow. This would mean sacrificing a ready catapult entirely free of the recovery area, i.e., restricting the types of aircraft which, when spotted on the catapult, would be clear of the recovery area. The safe parking area to starboard and forward of the recovery area would also be reduced.

Reductions in flight deck length can be achieved by restricting the types of aircraft that can be recovered. This reduces the length required for the recovery area. An "angled deck" configuration with some aircraft types excluded is shown in Figure 3. This deck has a total length of 813 feet and was developed for a small aircraft carrier design study. In this case, the distance labelled H-I in Figure 2 is equal to 25 percent of the hull waterline length, the length of the recovery area is 567 feet, and not all the aircraft that can be operated from the deck can be spotted on the starboard catapult and, at the same time, be clear of the recovery area. An even shorter deck could be developed by incorporating the same recovery area in an "axial" configuration at the sacrifice of all *simultaneous* launch and recovery capability.



MINIMUM ANGLED DECK CONFIGURATION II

- FOR CERTAIN LESS DEMANDING TYPES OF MODERN AIRCRAFT
- WITH ONE CATAPULT CLEAR OF RECOVERY AREA (NOT FOR ALL AIRCRAFT TYPES OPERABLE FROM DECK)
- 21 KNOTS MINIMUM WIND-OVER-DECK DURING RECOVERY

Figure 3.

If conventional aircraft are excluded from the Air Wing and only helicopters and VSTOL aircraft are considered, further flight deck size reductions can be visualized. Perhaps the extreme case would be a small landing pad for *one* helicopter or VSTOL aircraft, with only vertical landings and take-offs permitted. In reality, of course, a flight deck which permits VSTOL aircraft to make a deck run before take-off is generally desired and "longer is better." Another advantage of the short take-off over the vertical take-off for a given aircraft weight is that considerably less fuel is consumed during the evolution, and hence, the airborne aircraft has a longer mission range or loiter time. This increased capability can reduce the requirement for aerial refueling. In the arrangement of flight decks for VSTOL aircraft, providing the capability to make emergency "roll-on" recoveries is sometimes also a consideration.

Clearly there are a large number of minimum flight deck lengths, each corresponding to a particular set of requirements. Also, there are many factors which can significantly influence flight deck size which have not been mentioned in this brief discussion such as: number of catapults; length of catapult power stroke; number, locations and size of aircraft elevators; and required flight deck parking area.

Before discussing minimum carrier size in terms of full load displacement, the concept of a "balanced" carrier design will be introduced. Given a specific flight deck, a hull is required to support it which must contain machinery to propel it at the speeds required for aircraft launch and recovery. The hull cannot be too much shorter than the flight deck, and it must have adequate depth in order to provide adequate draft from the standpoints of satisfactory propeller immersion and keel slamming characteristics and to provide adequate free-board from the standpoints of satisfactory reserve buoyancy and seaworthiness characteristics. Further, adequate beam is required from the standpoints of satisfactory transverse stability and "machinery box" width characteristics. Thus, for a given flight deck there is a minimum hull size expressed in terms of length, beam, and depth. This minimum hull — with its internal decks and bulkheads; propulsion, electrical and auxiliary machinery; command, control, and communications systems; self-defense weapons systems; and outfitting — will weigh a very substantial amount even if protection features, aviation payload (aircraft, aviation ordnance, fuel, etc.), human support spaces, and consumables storerooms have not been incorporated into the design. At the same time, the hull will contain a large amount of unused internal space. Thus, for a given flight deck there is, in a sense, a corresponding minimum full load displacement as well as a minimum hull size. The addition of human support facilities, protection features, aviation payload, and other related items will tend to fill up the unused internal space in the hull and to increase the ship weight, but not significantly increase the hull size up to a certain point. A "balanced" carrier design, regardless of the selected protection features, is one in which the specified aviation payload and required crew size fully utilize the internal space in the minimum hull required to support the flight deck, but do not drive the size of the hull significantly beyond that minimum. A "balanced" design is the most efficient design. In order to achieve this goal in a new design, the internal space users, primarily aviation payload and related items such as personnel and consumable stores, must be tailored to the size of the required flight deck. In short, there is an optimum "balance" between aviation payload and flight deck size in every carrier design, large or small. This same point is made in another way in Reference [2].

A brief consideration of minimum carrier size in terms of full load displacement is now in order. The full load displacement of a "balanced" carrier design which incorporated the 912-foot long flight deck shown in Figure 2 would fall in the 60,000 ton plus range. Such a design would reflect a mix of modern protection features and would be capable of operating and supporting about 50 modern aircraft. However, active offensive and defensive capabilities would be greatly inferior to those of the *Nimitz* Class carriers.

As another example, the full load displacement of a "balanced" design reflecting the 813-foot long flight deck shown in Figure 3 would fall in the 35,000 ton range. Many modern aircraft types could *not* be operated from this ship, and the Air Wing would consist of about 30 aircraft. At this displacement, many modern protection features would not be incorporated in the design. Clearly there are a number of other "balanced" carrier designs which could be created in the 35,000 to 60,000 ton displacement range, each with its own unique combination of features and capabilities. The primary variables in this size range are: flight deck operational concept, Air Wing size, aircraft types which can *not* be operated, and protection features. It appears that the absolute minimum size carrier which is capable of operating *any* useful number of any useful types of modern conventional aircraft falls in the 30,000 ton size range. Below this size only VSTOL aircraft, helicopters, and piston-engined aircraft like those of the World War II era can be considered.

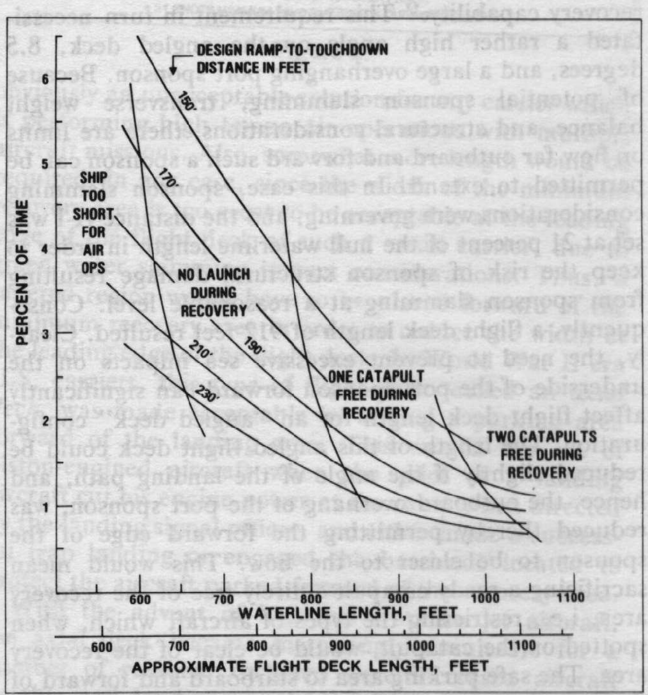


Figure 4. Percent of Time Air Operations are precluded by Ship Motions.

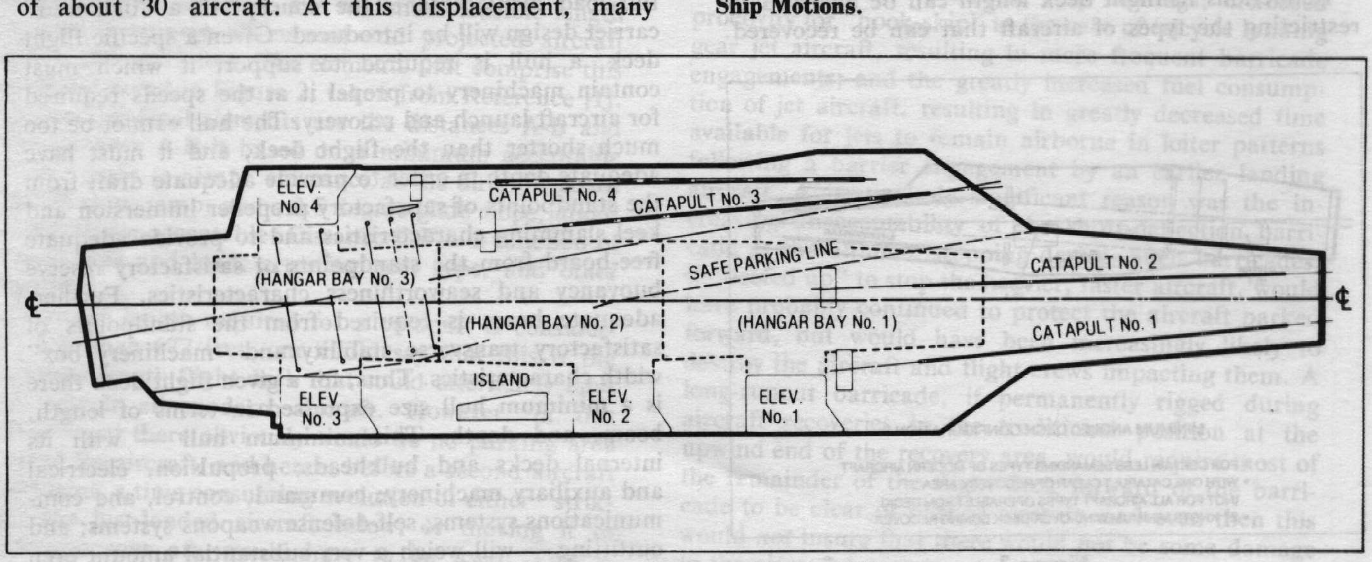


Figure 5. Current Configuration — CVN-68.

One very important additional consideration with respect to ship size relates to seaworthiness which, in turn, affects the percentage of time air operations are precluded by ship motion. Some improvements in seaworthiness are attainable by attention to detail design features, but these gains are small when compared to the seaworthiness improvements that accrue from increased ship size. Figure 4 shows the effect ship size has on ship availability as well as demonstrating the effect of varying the "ramp to touch-down" distance for both the axial and angled flight decks discussed so far. This plot, taken from Reference [3], is for a particular aircraft, type of arresting gear, wind over the deck, and for a certain assumed acceptable accident rate. Similar plots for different aircraft and alternate assumptions with regard to arresting gear configuration, wind over the deck, or accident rate, all show the accelerated degradation of ship availability for air operations as ship length is progressively reduced below 1,000 feet length overall.

Overall Configuration

All of the U.S. NAVY'S post World War II carrier construction has utilized the "angled flight deck" configuration. The most recent version of this configuration is shown in Figure 5, the *Nimitz* flight deck. There have been changes in catapults and arresting gear from one ship to the other, but the main visual differences among these ships are due to variations in the locations of the aircraft elevators. Commencing with the *Kitty Hawk* (CV-63), the port elevator was moved from a location forward of the two waist catapults to a point aft of them, and the positions of the island and the number two elevator were interchanged, resulting in two starboard elevators located forward of the island. There have been variations, usually minor, in internal arrangements that were necessitated by changing protection schemes, propulsion plant types, and aircraft maintenance and ordnance requirements. There are *two* basic ship lengths: 990 feet on the waterline for the fossil fueled steam plants, and 1,040 feet on the waterline for the nuclear fueled steam plants. From the above, one might arrive at the conclusion that the design of the U.S. NAVY'S carriers has become stereotyped. If this is true, it is not because many alternate schemes, some of which are quite radical departures, have not been investigated, but rather that no alternate proved sufficiently attractive to warrant its adoption. The following paragraphs set forth a few of the many alternative configurations that have been given consideration along with a summary of their primary advantages and disadvantages:

a) Figure 6 shows a *three* elevator configuration for a large deck that has an axial landing path entirely to port of the ship's centerline. The *advantages* of this configuration are: 1) Elimination of the port side elevator allows moving the shell outboard to enclose the port sponson, thereby providing considerably more useful internal deck area; 2) Landing aircraft encounter reduced air turbulence due to the fact that the ship can steam directly into the wind during air operations, and also due to the island being more remote from the landing path; and 3) Greater clearance around the arresting gear is provided, and hence, installation of this equipment would be easier than in the carriers from *Kitty Hawk* Class on, where this space is restricted between the Number 3 elevator to starboard and Number 4 to port. The *disadvantages* are: 1) Back-up capability and aircraft handling flexibility are decreased by the removal of one elevator. Also, a port side elevator is not available when heading and wind/sea conditions favor that side; 2) Vulnerability to damage is increased by having all the elevators on *one* side of the ship; 3) A loss of one ready catapult during aircraft recovery results; and 4) The axial deck creates a design problem for self-defense armament installation on the port quarter.

b) Figure 7 shows a dual recovery configuration with *two* independent aircraft recovery areas. The *advantages* of this configuration are: 1) Recovery time can be

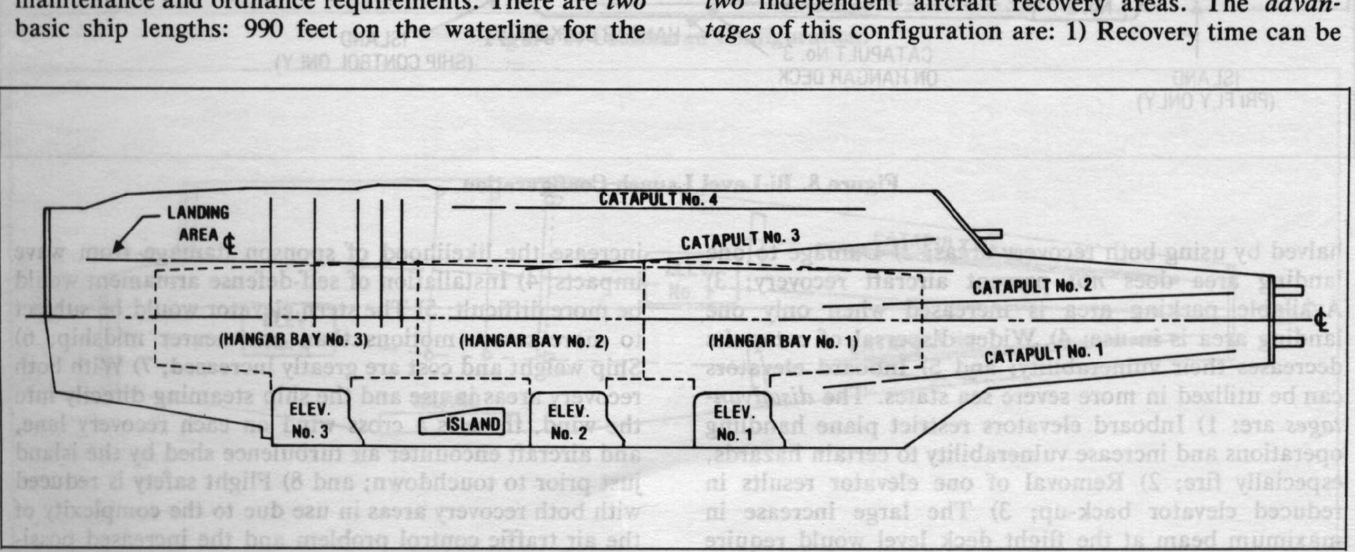


Figure 6. Three Elevator Configuration.

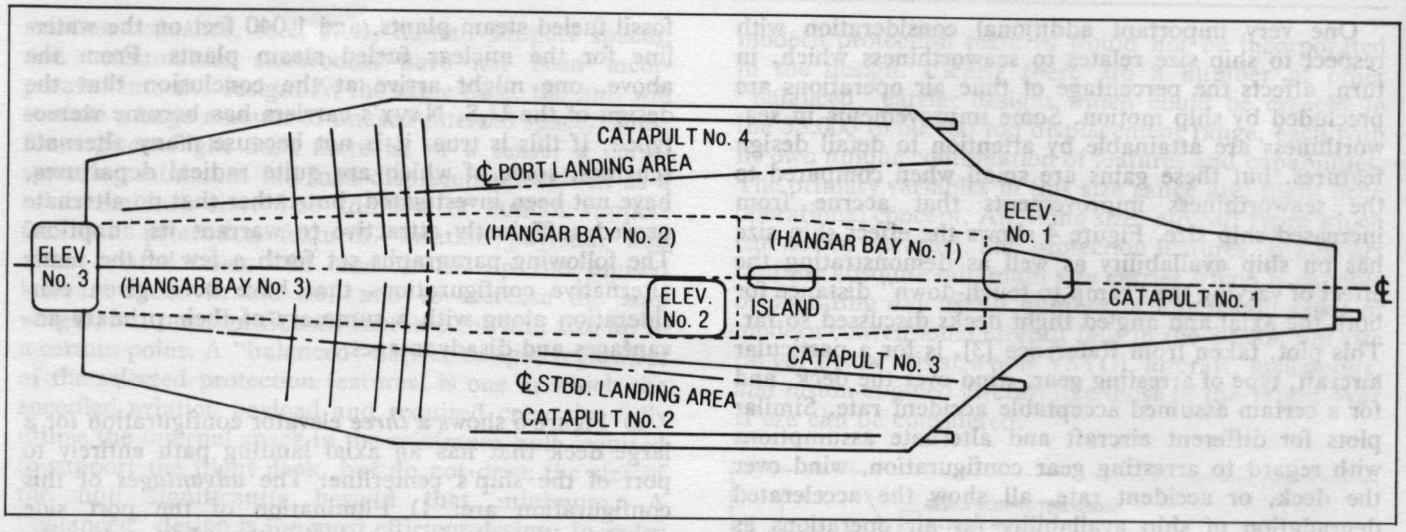


Figure 7. Dual Recovery Configuration.

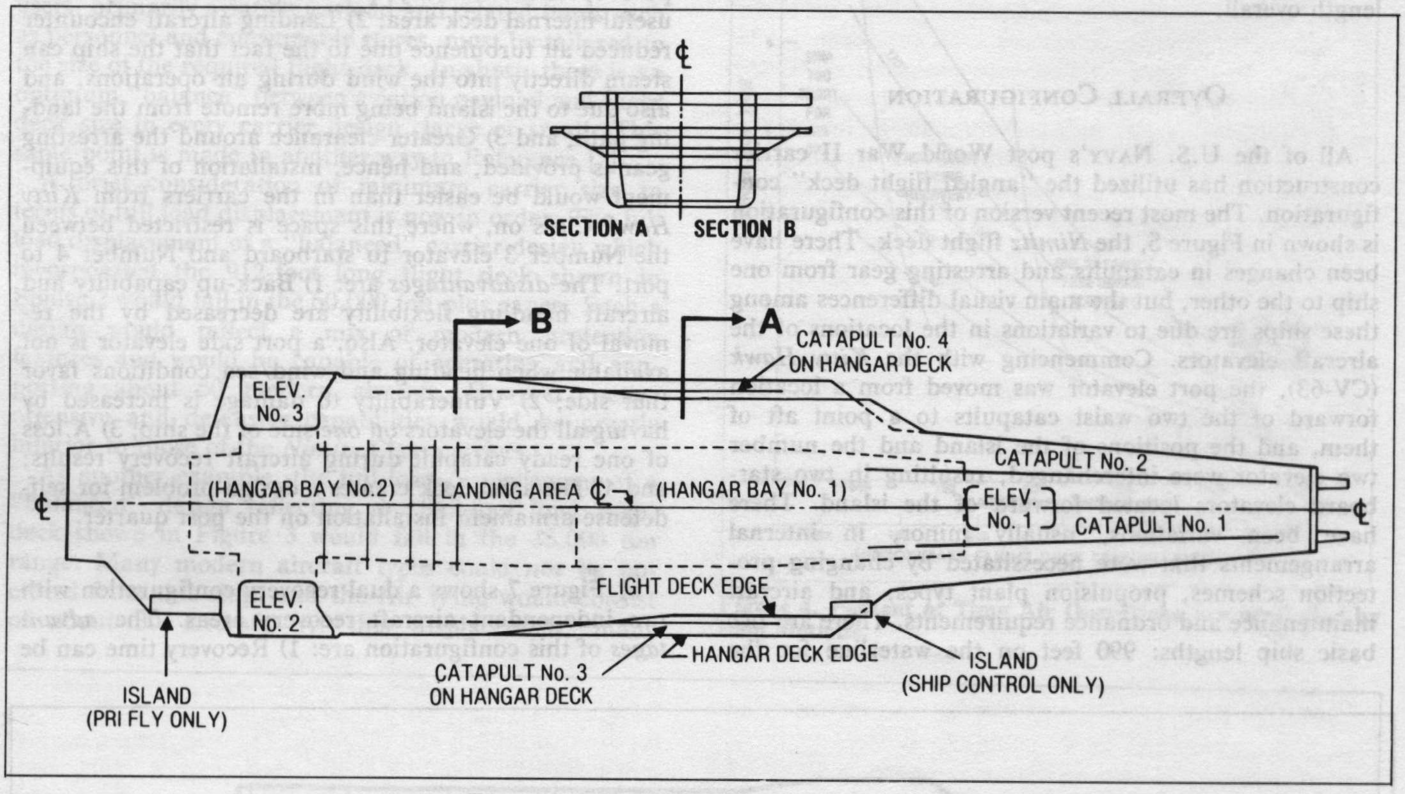


Figure 8. Bi-Level Launch Configuration.

halved by using both recovery areas; 2) Damage to one landing area does *not* prevent aircraft recovery; 3) Available parking area is increased when only one landing area is in use; 4) Wider dispersal of catapults decreases their vulnerability; and 5) Inboard elevators can be utilized in more severe sea states. The *disadvantages* are: 1) Inboard elevators restrict plane handling operations and increase vulnerability to certain hazards, especially fire; 2) Removal of one elevator results in reduced elevator back-up; 3) The large increase in maximum beam at the flight deck level would require major revisions in construction and repair facilities and increase the likelihood of sponson damage from wave impacts; 4) Installation of self-defense armament would be more difficult; 5) The stern elevator would be subject to more severe motions than one nearer midship; 6) Ship weight and cost are greatly increased; 7) With both recovery areas in use and the ship steaming directly into the wind, there is a cross wind on each recovery lane, and aircraft encounter air turbulence shed by the island just prior to touchdown; and 8) Flight safety is reduced with both recovery areas in use due to the complexity of the air traffic control problem and the increased possibility of pilot disorientation.

c) Figure 8 shows a bi-level launch configuration with *two* catapults at the hangar deck level. The *advantages* of this configuration are: 1) Two ready aircraft can be maintained entirely clear of the landing and parking areas; 2) The lower level catapults are less vulnerable to bomb damage; 3) The landing area is axial; 4) Inboard elevators can be utilized in more severe sea states; and 5) The need for upper stage ordnance "strikeup" is eliminated for aircraft launched from the hangar deck. The *disadvantages* are: 1) The deck edge elevators must be in the "down" position to move aircraft from the hangar to the lower catapults; 2) Aircraft on the lower catapults are not in view from the primary flight control station thereby requiring reliance on closed circuit TV for observation; 3) The forward inboard elevator would have limited usefulness and, if damaged or inoperable and in the "down" position, would be hazardous to "bolters"; 4) Recovery rate would be reduced by the need to move aircraft that have just landed to port and starboard sponsons amidships in order to clear the recovery area; 5) Launching rate for the catapults at the hangar deck level would be reduced by the lack of multiple clear areas for aircraft "start-up" and "check-out"; and 6) Spray and green water would be likely to prevent use of the lower catapults at times.

d) Figure 9 shows a catamaran configuration. The *advantages* of this configuration are: 1) A back-up landing area is provided; 2) Launch and recovery operations conceivably could be carried on simultaneously on opposite sides of the ship; and 3) Flight deck area is greatly increased without resort to extensive sponsons. The *disadvantages* are: 1) Inboard elevators increase vulnerability to bomb and fire damage; 2) Catamarans

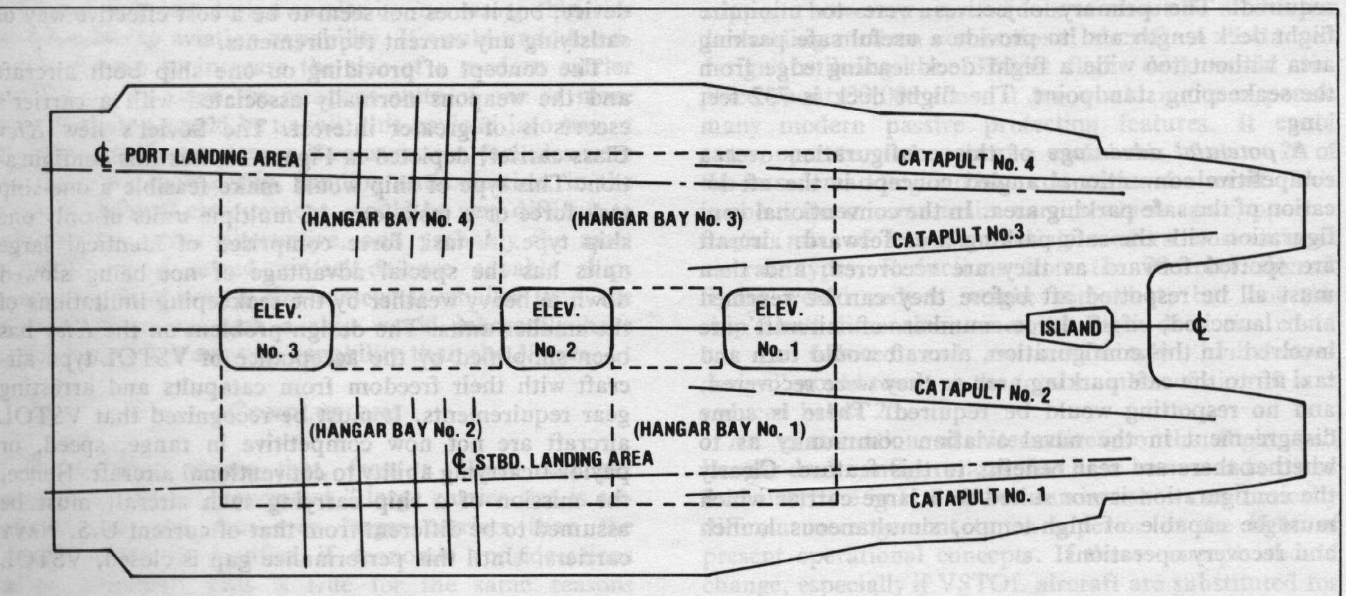


Figure 9. Catamaran Configuration.

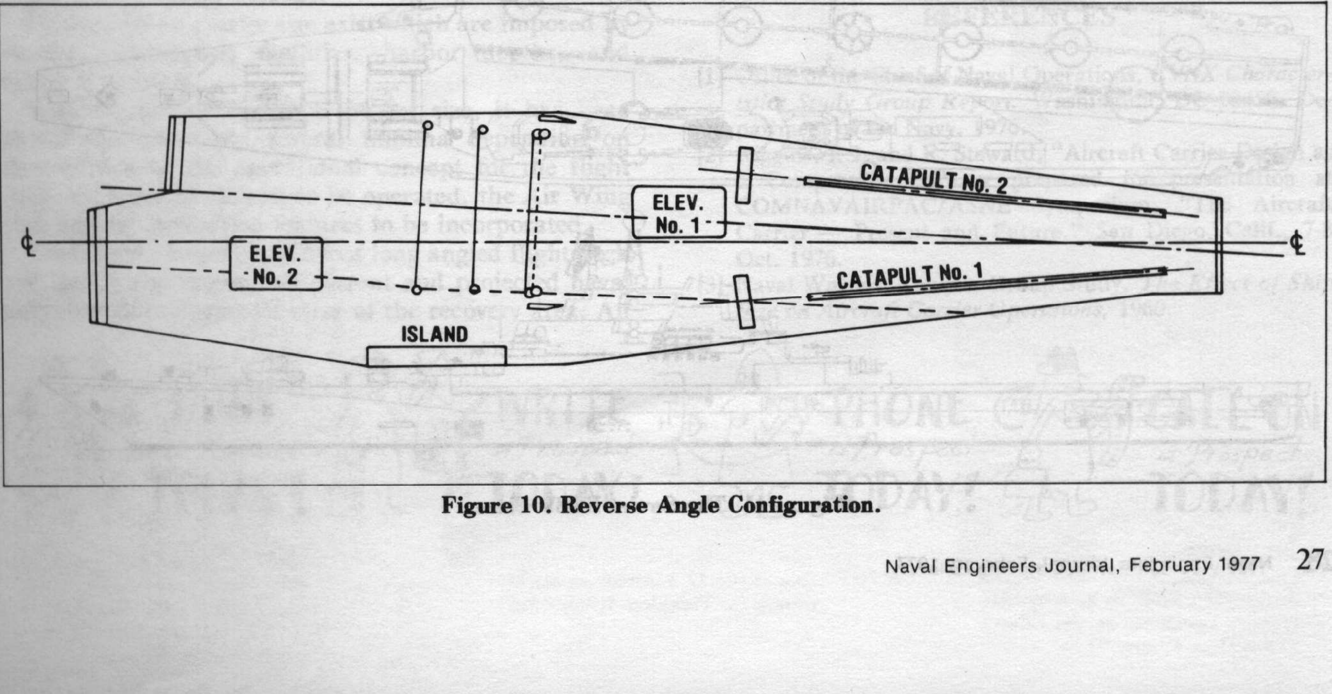


Figure 10. Reverse Angle Configuration.

have greater resistance to forward motion than monohulls in the length and speed regime likely to be of interest; 3) Open ocean catamarans of the required size have *not* been built and would require extensive research in structure, seaworthiness, and damaged stability; 4) Ship weight and cost is greatly increased; and 5) Major revisions in construction and repair facilities would probably be required by the large flight deck beam and twin hulls.

e) Figure 10 shows a so-called "reverse angle" configuration developed for a minimum sized carrier study. A number of current aircraft types could not operate from this deck. Inboard elevators were utilized due to the low hangar deck freeboard, but they are not an inherent feature of the concept. In this study, low-tempo aircraft operations were assumed and a simultaneous launch and recovery capability was not required. The primary objectives were to minimize flight deck length and to provide a useful safe parking area without too wide a flight deck leading edge from the seakeeping standpoint. The flight deck is 732 feet long.

A *potential advantage* of this configuration over a competitive conventional angled concept is the aft location of the safe parking area. In the conventional configuration with the safe parking area forward, aircraft are spotted forward as they are recovered, and then must all be respotted aft before they can be rearmed and launched, if a large number of aircraft are involved. In this configuration, aircraft would turn and taxi aft to the safe parking area as they were recovered, and no respotting would be required. There is some disagreement in the naval aviation community as to whether there are real benefits to this feature. Clearly the configuration is *not* suited to a large carrier which must be capable of high-tempo, simultaneous launch and recovery operations.

The full load displacement of a "balanced design" reflecting the 732 foot long flight deck shown in Figure 10 would fall in the 30,000 ton range. Many current aircraft types would be excluded by the austerity of the flight deck, and the Air Wing would consist of about 20 aircraft. The design would not incorporate many modern protection features at this displacement.

Two other interesting aircraft carrier configurations are also worth mentioning. It has been proposed in the past to construct *submersible* aircraft carriers, and also to configure our carriers to reflect more emphasis on shipboard weapons systems, i.e., to reflect a more even balance between aircraft and shipboard weapons systems in the total payload. With respect to the submersible type, this is obviously the most expensive way of basing aircraft at sea, and it is feasible only for one, or at the most, several aircraft per ship. This might have been attractive in the past as a reconnaissance device, but it does not seem to be a cost effective way of satisfying any current requirements.

The concept of providing on one ship both aircraft and the weapons normally associated with a carrier's escorts is of greater interest. The Soviet's new *Kiev* Class carrier, depicted in Figure 11, has this configuration. This type of ship would make feasible a one-ship task force or a task force of multiple units of only one ship type. A task force comprised of identical large units has the special advantage of not being slowed down in heavy weather by the seakeeping limitations of the smaller units. The design problem on the *Kiev* has been simplified by the acceptance of VSTOL-type aircraft with their freedom from catapults and arresting gear requirements. It must be recognized that VSTOL aircraft are not now competitive in range, speed, or payload-carrying ability to conventional aircraft. Hence, the mission of a ship carrying such aircraft must be assumed to be different from that of current U.S. Navy carriers. Until this performance gap is closed, VSTOL

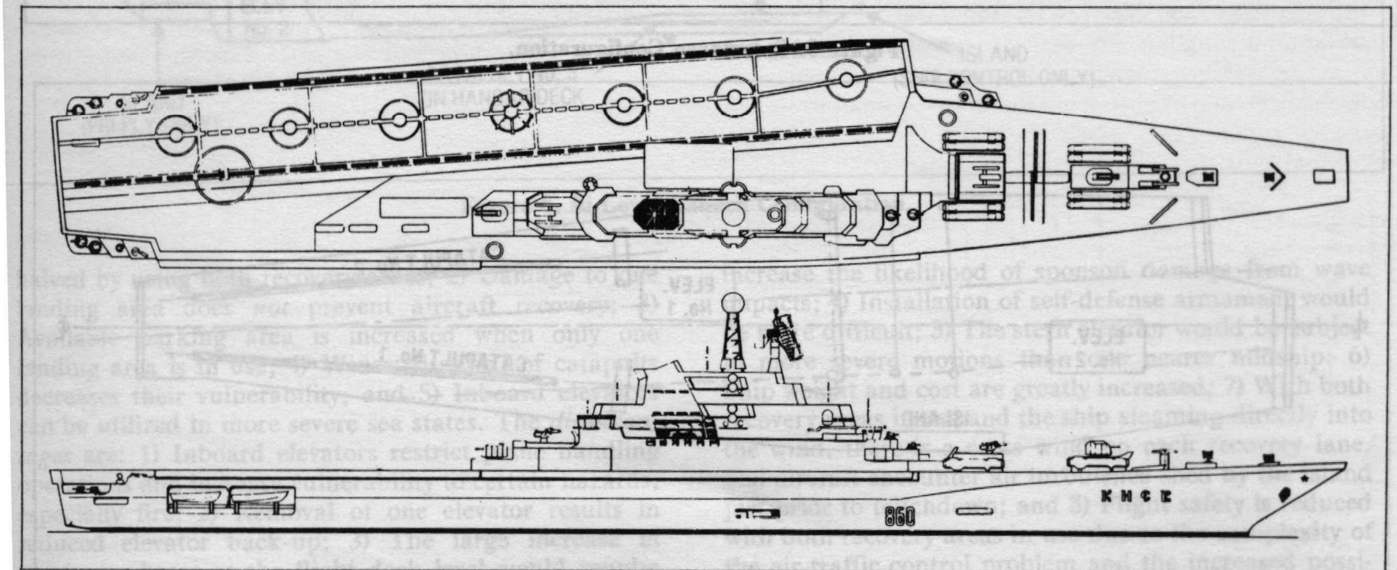


Figure 11. The Soviet KIEV Class.

aircraft carriers *cannot* be considered as viable alternatives to conventional carriers with catapults and arresting gear.

The argument for adding escort-type ASW and AAW armaments to carriers must rest first on whether the range, speed, and response time of the weapons and sensors under consideration are such that no appreciable advantage accrues from their being on the carrier escorts and hence nearer their targets. This has not been true in the past, but with the developmental new weapons systems this may be changing. If one were to add the weight, volume, and deck area associated with additional armaments to new design carriers without sacrificing any current aviation capability, either larger or more crowded ships would obviously result. Aircraft carriers are already volume critical, and the demand of their designers compromises in habitability and accessibility. Hence, added weapons could only be accommodated in a new design carrier by *increasing* ship size or by *reducing* aviation capability. It would undoubtedly be cheaper to increase the size of a modern carrier sufficiently to carry the weapons suite of one or more escorts than it would be to split this payload into two or more ships. However, even if construction facilities were available for such a ship, funding authorization, in the present political environment, would be very difficult to obtain. The other alternative, and probably the most realistic for a mixed air/self-defense capable ship, would be to aim at a size somewhat smaller than the *Nimitz.* However, such a ship would inherently have significantly less aviation capability than the *Nimitz.*

CONCLUSIONS

It has been shown that, from a "least cost per embarked aircraft standpoint," large carrier size is advantageous, and that even larger carriers than the *Nimitz* could be justified if economic considerations alone governed. This is true for the same reasons applicable to merchant ships, but with the important additional advantage gained in the ratio of protected magazine volume to protection cost, in weight and space, for the larger carriers.

Constraints on carrier size exist which are imposed by current construction facilities, harbor depths, and bridge clearances.

With respect to minimum carrier size, it has been shown that there are several minima depending on factors such as the operational concept for the flight deck, the types of aircraft to be operated, the Air Wing size, and the protection features to be incorporated.

Considering length, a 912-foot long angled flight deck can launch and recover all current and projected naval aircraft with *one* catapult clear of the recovery area. An 813-foot long angled flight deck can launch and recover a useful mix of less demanding modern conventional aircraft types, but not all of these aircraft types can be spotted on the starboard catapult and be clear of the recovery area. Even shorter decks could be developed if the capability of simultaneous launch and recovery were sacrificed completely and an axial or so-called "reverse angle" configuration were adopted. An example is the 732-foot long flight deck depicted in Figure 10.

Considering full load displacement, a "balanced design" utilizing the 912-foot long flight deck would displace somewhat more than 60,000 tons. The design would reflect modern protection features and could carry, operate, and support a typical mix of about 50 modern aircraft. A "balanced design" utilizing the 813-foot flight deck would displace about 35,000 tons. This design would *not* incorporate many modern passive protection features. It could carry, operate, and support, however, a useful mix of about 30 of the less demanding modern conventional aircraft. A "balanced design" utilizing the 732-foot flight deck would displace about 30,000 tons. It too would *not* incorporate many modern passive protection features. It could carry, operate, and support a useful mix of about 20 of the less demanding modern conventional aircraft. This is about the minimum size carrier which can support a *useful* mix of less demanding modern conventional aircraft types. Reductions from the 20 total aircraft figure would reduce weight somewhat, but not the ship's hull dimensions since the flight deck size could not be reduced and an increasingly "unbalanced design" would result as the total number of aircraft was reduced below 20.

An examination of alternatives to the flight and hangar deck configurations that have been standardized for some time in U.S. NAVY carriers shows no basically different arrangement to be superior in the light of present operational concepts. If these concepts should change, especially if VSTOL aircraft are substituted for conventional aircraft requiring catapults and arresting gear, then alternatives do become attractive.

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