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**THE DESIGN OF HMS QUEEN ELIZABETH AND HMS PRINCE OF WALES**

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**ABSTRACT**

The paper describes the evolution of the United Kingdom’s new aircraft carriers HMS Queen Elizabeth and HMS Prince of Wales ~ the biggest warships ever to be constructed by the UK. It addresses some of the fundamental drivers on the principal dimensions, form, arrangement and overall configuration of the ships and then proceeds to describe the three fundamental iterations of the design, resulting in the so called DELTA design ~ the configuration presently under construction at various shipyards in the UK. The paper discusses the reasons for the overall configuration of the carriers including the twin island arrangement, the deck edge lifts, the location and size of the hangar, and the power and propulsion configuration.

**INTRODUCTION**

The aircraft carrier poses a unique naval architectural challenge to the designer. The requirements for speed, stability and seakeeping ability as well as the complex spatial interactions between flight and hangar decks, accommodation arrangements, operational and air weapons spaces mean that the ‘optimum’ aircraft carrier for one parameter is invariably a compromise for another.

This paper presents the evolution of the design of the UK CV Adaptable Aircraft Carrier with the focus upon the early concept/feasibility studies to determine its overall size and configuration. The paper then proceeds to describe the three fundamental iterations of the design, resulting in the so called DELTA design ~ the configuration presently under construction at various shipyards in the UK.

The paper is subdivided into two principal sections:

- The evolution of the design which addresses the principal drivers on the overall size of the ship, the possible options and configurations to meet the competing requirements, and the design policies and tenets set in place at the outset of the design;

- The ‘baseline’ designs, presenting the three fundamental iterations of the design, describing the overall form, arrangement and principal features.
THE REQUIREMENT

Programme Technical Considerations

One of the major outcomes from the UK Strategic Defence Review in 1998 was the requirement for two large new aircraft carriers to replace the three INVINCIBLE Class carriers currently in service with the UK Royal Navy. The programme of work developed by the MOD Integrated Project Team following this review, envisaged a four and a half year Assessment Phase. In this Assessment Phase various options meeting a user requirement would be assessed, and this would culminate in the award of a Design and Manufacture contract in 2008, with the in service date for the first ship being 2014 and the second 2016. This extended assessment phase reflected the then uncertainties over the primary aircraft that the carriers would be required to carry and operate. At the commencement of competitive industry studies in 1999 by potential Prime Contractors BAE Systems and Thales, the aircraft was known as the Future Carrier Borne Aircraft (FCBA) and could potentially have been one of three generic variants – CV (Catapult launch and arrested recovery), STOBAR (Short Take Off But Arrested Recovery) or STOVL (Short Take Off Vertical Landing). Studies thus commenced on ship designs for all three variants for a range of carrier air group (CAG) numbers with the principal aims of:

- Informing the FCBA COEIA (Combined Operational Effectiveness and Investment Appraisal) of the ship implications of the potential options;
- Understanding the costs of the overall UK aircraft carrier programme of work;
- Clarifying the User Requirements;
- Determining the critical design features and design drivers for the different carriers.

In 2001 the Joint Strike Fighter was selected as the preferred generic aircraft solution. This decision effectively eliminated the STOBAR variant from the UK Requirement and thus more detailed Stage 2 Assessment Phase studies by both potential Prime Contractors concentrated on the production of two designs each, one for CV and one for STOVL (with similar CAG numbers). When the decision was made to adopt the STOVL variant of the JSF in September 2002, a decision was also made to take forward the CV variant of the ship as the STOVL platform, to be easily reconfigured for CV operations later in the ship’s life. This allowed the two competing industry teams to focus upon a single design for the remainder of Stage 2 Assessment until the end of 2002.

In mid 2003 the first fundamental iteration of the design took place. This was in response to competing cost constraints, which resulted in a smaller less capable design. By Christmas 2003, it was realised that this smaller design would not be able to meet all User aspirations and thus the principal dimensions were increased to provide more deck area and volume. These principal dimensions have remained unchanged since then. By mid 2006, the design had sufficiently matured to allow accurate cost estimates from all Alliance Partners to be obtained; this showed a
worrying increase and it was thus decided to modify a number of the design policies and standards which while not changing the form or arrangement, would result in a decrease in cost at the expense of slightly modified equipment and system capability.

The manufacturing contract for the 2 x aircraft carriers was finally awarded in July 2008, and fabrication of the bow section of the lead ship commenced in January 2009.

User Requirements

The original User Requirements for the carrier were derived from nine High Level Characteristics (HLCs) which were themselves derived from a single statement of mission need. This statement is that the CVF is to be a “Joint defence asset with the primary purpose of providing the UK with an expeditionary offensive air capability which has the flexibility to operate the largest possible range of aircraft in the widest possible range of roles”. The HLCs are:

- Interoperability;
- Integration;
- Availability;
- Deployability;
- Sustainability;
- Aircraft operation;
- Survivability;
- Flexibility;
- Versatility.

Under the then ethos of SMART Procurement, these characteristics were decomposed into a relatively small number of User Requirements which are quantified by minimum and desired performance levels, these allowed the designers to explore the trade space and offer levels of performance which most sensibly met the cost and programme goals of the Project.

Within these User Requirements there are a number which critically impact the overall size of the carrier and these are generally in the Aircraft Operation, Deployability, Sustainability and Survivability HLCs, specifically the carrier is required to achieve:

- A minimum number of aircraft sorties and a minimum sortie generation profile;
- A minimum deck alert profile;
• Minimum times to launch and recover specified numbers of aircraft;
• Aircraft stowage and maintenance;
• Minimum ship range and endurance;
• Minimum levels of survivability.

These requirements were studied during the concept/feasibility design phase to produce a carrier which most cost effectively met the requirement. This design was subsequently described in a Ship or Product Specification, which now forms the basis for the Carrier contract.

EVOLUTION OF THE DESIGN

Introduction

When design studies commenced in 1999 the team was thus required to produce designs for 3 generic carriers - CV, STOVL or STOBAR for a range of CAG numbers. Building upon past work carried out by the UK MoD (by the now defunct Directorate of Future Projects [Naval] as reported by Groom et al in 1997 ¹ and by examination of current and past UK and foreign carriers and carrier designs (in particular CVA01 and Nimitz Class carriers were assessed) an appreciation was quickly built up of some of the fundamental drivers of the design of the carrier. These were determined to be:

• The arrangement and the gross size of the flight deck;
• The interaction between the flight and hangar decks;
• The compromise between sea keeping and stability performance;
• The arrangement of the major spaces and their interaction with the flight and hangar decks (especially air weapons, magazines and machinery spaces).

In addition to this (and this also applies to any ship design), fundamental decisions needed to be taken on design policies, standards, survivability, margins, and environmental issues (among others).

The Flight Deck

Even for someone who has not witnessed flight deck evolutions at first hand, it is not difficult to appreciate that operating aircraft safely from flight decks is an incredibly difficult scenario to achieve which requires very careful planning and

¹ Groom et al Warship 1997 International Symposium: Air Power at Sea, RINA
immensely careful design. For CV and STOVL arrangements, there are a number of factors to be considered:

- The length of the catapult or runway and the requirements for safety clearance lines;

- For simultaneous launch and recovery, the requirement to keep the launch runway clear of the recovery area by a suitable safety margin;

- The length of the recovery runway and recovery area (balancing the requirements of aircraft approach speed, acceleration forces, aircraft strength and recovery equipment strength [for a CV]);

- The area available for aircraft parking and its necessary safety clearance from launch and recovery operations (including parking requirements for an Alpha strike);

- The flow of aircraft on the flight deck to limit the movements required between recovery, aircraft turnaround and launching;

- The interaction with the aircraft lifts;

- The location of the island or superstructure for the siting of sensors and communications equipment, uptakes and operational spaces.

Figure 1 [a-c] shows some indicative views of how the CV flight deck evolved while Fig 1 [d-f] shows the STOVL variant. Fig 1a is a 2-catapult design with integral single aircraft lifts, a single island and a 3 wire arrestor system (with barricade on the third arrestor engine); this design suffers from a poor aircraft flow regime due to the locations of the aircraft lifts.

![FIG.1A – 2 CATAPULT DESIGN, INTERNAL LIFTS](image1)

![FIG.1B – 3 CATAPULT DESIGN, 2 DECK EDGE LIFTS](image2)
Fig 1b is a 3-catapult design with 2 deck edge lifts sized for two aircraft, and a single island; whilst in theory achieving a good launch rate, this design will be inhibited by lack of parking area (even with the addition of deck edge lifts) leading to considerable congestion on the flight deck. Fig 1c is a 2-catapult design showing 2 deck edge lifts, one located port and the other starboard, and with a twin island solution, both islands located forward. The parking area has increased but the aircraft flow regime is still not ideal.

Fig 1d is a two runway configuration with deck edge lifts and the landing spots integral with the port runway. This arrangement suffers from a poor flow regime for the aircraft. The design in figure 1e attempts to separate the launch from the recovery area such that there is a genuine flow to the movement of aircraft on the flight deck - recover - turnaround - launch, similar in concept to the design of the CVA01. It thus has a runway at the starboard side of the island, recovery spots on the port side of the ship, and integral lifts located at the centre line of the vessel.

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Figure 1f shows a twin island design with two runways converging to an integral ramp and loading spots on the port side. This design demonstrates adequate parking, makes good use of the ramp for both runways and achieves a good flow regime.

It should be noted that even at this early stage in the design, both CV and STOVL designs were tending towards similar overall dimensions in terms of flight deck requirements. The current CV Adaptable flight deck, as described later, built very much upon these early concepts many of which were subsequently modified and validated by simulation (using tools such as SAILOR [A computer based tool developed by THALES for assessing sortie generation rates]).

**Hangar**

**Gross Arrangement Options**

In the same manner as the flight deck design evolved in an iterative manner, so too did the design of the hangar. The requirements called for space for 26 aircraft to be accommodated in the hangar in stowage boxes (with greater capacity in nested stowage) and this left considerable flexibility as to how the hangar could be configured. The issue is not one of simple area allocation but of length, width and height of hangar and its critical interfaces with the flight deck and the aircraft support infrastructure. With typical aircraft widths (CV and STOVL variant aircraft have similar widths because even though the CV variant wing spans are greater, they do fold) of 12m, including stowage boxes dimensions, this means that stowing aircraft in the hangar indicated hangar widths with deltas of 12 meters each time an aircraft is added. As discussed later, the beam of the carrier is critical from seakeeping and stability viewpoints and this placed a major constraint on the arrangement of the hangar. With this constraint in mind there were then the global issues of the location of the hangar within the overall geometry of the ship. Typical aircraft carriers have their hangars located high in the ship and extending as far forward and aft as practicable; they may also be either immediately below the flight deck or separated from the flight deck by a so called “gallery deck” which accommodates launch and recovery equipment and operational and accommodation spaces as appropriate. However some past carriers, most notably the UK’s conventional carrier ‘Ark Royal’ which was designed in the 1940s (and scrapped in the early 80s) had a split hangar extending over two levels with a total height of approximately 12 metres. As well as the stowage of aircraft, the hangar also needs to accommodate the air support and maintenance spaces. For the JSF the aircraft is typically embarked with all its spaces and supporting equipment in containers - a modular support philosophy, which are embarked using lorries when the vessel is in port. Thus suitable spaces also need to be found on the hangar deck to accommodate a larger number of containers, which could be readily accessed.

Another critical decision in the design of the hangar is its height which is a function, not just of the height of the aircraft to be stowed but also the types and frequency of aircraft stowage and maintenance requirements, any deckhead stowage requirements and the integration with the rest of the ship. Because space in any ship is at a premium it could be that the best use of space is not to have a single height of hangar which will allow deep maintenance anywhere (e.g. such as

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the removal of rotors on helicopters), but to have localised “high hats” with maintenance spaces immediately adjacent.

Figure 2 shows some of the early hangar configurations considered.

**FIG.2 – SOME EARLY HANGAR DECK CONFIGURATIONS**

**Lift Locations and Types**

The principal interaction between the hangar and flight deck is via the aircraft lifts. Ideally the lifts should have minimal impact on flight deck operations and are thus best located at the edges or extremes of the ship. However, deck edge lifts will be vulnerable to damage from heavy seas and thus typically deck edge lifts are only incorporated on larger aircraft carriers. Aircraft lifts internal to the structure of the ship will not suffer from this seakeeping problem, but they do have other critical disadvantages:

- Unless arranged very carefully, they will impact flying operations (especially if not operating);
- They consume valuable hangar deck area and interrupt the flow of aircraft within the hangar.

Aircraft lifts also need to be located very carefully relative to the arrangements of the hangar to ensure they can be accessed from as many locations as possible, and that a damaged aircraft, or aircraft in deep maintenance, will not block the access to the lift of serviceable aircraft. Figures 1a – f and 2 show some of the issues.

**Sea Keeping and Stability**

a) Ship motions

Seakeeping motions are critical to aircraft operations on ships, not only for launch and recovery but also for aircraft movement, support and ordnance handling.
Whilst pitch motions are a function principally of ship length, roll motions are a
function of the beam and the vertical centroid of gravity of the ship. Experience
has shown that aircraft carriers with roll periods of less than about 20 seconds (as
particularly evidenced by the USS Midway in 1986, which had a blister added to
improve stability and survivability \(^2\) exhibit excessive motions and deck wetness
which will limit flight deck operations. The addition of bilge keels and anti roll
stabilisers will only marginally impact the roll period and thus the critical
parameter is the metacentric height i.e. the beam of the ship and the vertical
centroid of gravity (VCG).

b) Through Life Growth

The UK and other Navies have learned to their cost the impact of weight and
centroid growth of their warships. Vessels designed for 30 years of life are
typically at sea longer than this and throughout their lives see almost constant
growth as well as changes in equipment specification, particularly topside
equipments, as communications equipment and sensors become ever more capable
and sophisticated. Aircraft carriers are not immune to this change and have the
added complication of fundamental changes to their primary payload as new
aircraft come into service. Some carriers are now operationally limited due to
their weight growth. It is of course arguable as to whether the limit in terms of
weight and size of manned jet engined aircraft operating from aircraft carriers has
now been reached, but it is inarguable that weight growth will occur. The only
issue is how much!

Recognising this, the requirements call for weight growth margins of up to 16%
throughout the life of the vessel and a VCG growth margin which halves the start
of life metacentric height, requirements which impact not only stability issues but
also structure, power and space.

c) Stability

The requirement for a relatively long roll period means that a relatively low value
of GM is required, a figure of approximately 2.5 metres being typical. GM is of
course one of the major parameters impacting the overall stability of the vessel
which is primarily quantified by the righting lever/heel angle curve, and thus a
figure of GM which is too small will mean that the stability requirements will be
difficult to achieve. This is the essential problem with aircraft carriers (and other
ships) - the requirements for sea keeping performance and the opposing
requirements for stability. This issue is compounded by the through life growth
issue so that while a sensible compromise may be achieved at start of life, the
reduction in GM through life may mean that the stability criteria may not be
achieved later in life. Conversely, the carrier could be designed with non optimum
motions at the start of life so that the stability criteria can be achieved at the end of
life. To add further complication, the issue is also a critical function of design
maturity. Weight and centroid data, as every naval architect knows, is notoriously
difficult to accurately estimate and there are real dangers in either over or under
estimating or in allocating incorrect margins. If this proves to be the case, the only
credible solution is to modify the beam of the ship, and this can have serious
repercussions on the overall design.

\(^2\) PATTISON, J. H. & BUSHWAY, R.R. ‘Deck Motion Criteria For Carrier Aircraft

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For the CV Adaptable design this very issue necessitated reduction in beam of the vessel by approximately 2 metres during feasibility studies in order to meet the necessary stability and sea keeping requirements.

The Arrangement of Major Spaces

a) Introduction

Whilst the arrangement of the flight deck and the size and location of the hangar are key to the success of the design of the aircraft carrier, key too are the integration of these features with the other operational, machinery, accommodation, stores and tankage spaces within the ship, which themselves strongly interface with the final location of the carriers superstructure or island. Figure 3 shows some of the early options considered by the team.

![Figure 3 - Some Major Space Integration Options Considered for the CVF](image)

b) Main Machinery

Integrated electric propulsion (IEP) was adopted very early in the design studies and is becoming increasingly the norm in the marine industry. IEP provides the flexibility to locate the power generators anywhere within the ship since they do not need to be tied to shaftlines located deep in the ship. However gas turbine driven alternators and diesel driven generators come with their own constraints in terms of adjacency to other compartments and integration with the ship. Gas turbines require an enormous quantity of air to operate and thus require large uptakes and downtakes to route the air from the intakes (located in a suitably clean and sea spray free environment) to the downtakes, to the engines, to the uptakes and thence to the funnels. The selection and the routing of these uptakes and downtakes has a big spatial impact on the ship and thus the ideal is to locate them as close to their engine as possible. However, on an aircraft carrier there is little available real estate high in the vessel and ideally (from an aircraft perspective) very little superstructure.
Particularly critical in the design of the carrier is the location of both the intakes and the funnels. Experience on the UK Invincible class carriers has indicated that for a STOVL ship, locating intakes on the port side of the vessel results in considerable corrosion problems at the intakes since the STOVL aircraft typically hovers adjacent to the vessel on the port side over the sea prior to landing, thus throwing up large quantities of sea spray which is ingested into the intakes. Similarly the location of the uptakes is important for aircraft operations for two principal reasons:

- Their physical impact on flight deck space which is at a premium;
- The effect of the hot efflux gasses and particles on aircraft engine performance.

There are precedents on aircraft carriers where the exhaust gases from the power generator engines have not been routed through uptakes to funnels in the superstructure but to outtakes at the side of the ship (some of the Japanese carriers of World War II which also had port side islands).

If it is assumed that the uptakes must pass to funnels in the superstructure then to limit the routing of the uptakes/downtakes the engines should be located in the same section of the ship as the superstructure. However for survivability reasons it is sensible to separate the power generators, thus pushing the funnels as far apart as possible, increasing the footprint on the flight deck and impacting flying operations the further this after funnel is moved aft.

c) Superstructure

For aircraft movement and physical launch and recovery operations the ideal is to have no superstructure on the flight deck at all. However a superstructure is required for the following reasons:

- For ship navigation purposes requiring the greatest possible unimpeded view of the ship and the surrounding sea;
- For flight control purposes requiring the greatest field of vision of the flight deck and the surrounding air space;
- To locate sensors and communications equipment with the widest area of coverage;
- To route uptakes and funnels to be as clear of the ship as possible.

If the carrier must have a superstructure then it needs to be located as far forward as possible or as far aft as possible, commensurate with remaining clear of aircraft recovery areas. However too far forward is difficult to integrate physically with the ship and prone to damage in heavy seas, and too far aft will limit the field of vision of the navigators, potentially impede air operations due to air wake and be a significant physical danger to recovering aircraft.

It is thus generally viewed that locating the island as far forward as practicable, within the constraints mentioned above is about the best location from a flight deck perspective. Also from that perspective it is important to keep the island
footprint as small as possible in order to maximise flight deck area, however the requirement to locate uptakes, sensors and communications equipment forces the island to be larger, and the issues associated with the length of the uptakes and downtakes dictate that the island should ideally be located as close as possible to the main machinery spaces. In addition, to restrict mutual interference, the ships sensors and communications equipment should be located as far apart as possible. These issues generally tend towards the conclusion that a twin island arrangement for a big ship with a large number of uptakes is probably the best compromise to the competing requirements for space.

d) Air Weapons

Advances in aircraft technology have been matched by advances in air weapons technology and with this comes an associated increase in variations in size and packaging. This places a number of constraints upon the stowage and movement of the weapons. Among the major issues are:

- Stowage of weapons in areas protected from external threat;
- Sensitivity of weapons to detonation;
- Extent of preparation of weapons prior to attachment to aircraft;
- Movement of weapons from their point of embarkation to stowage, then to preparation and attachment to aircraft;
- Constraints on the proximity of certain other compartments to magazines.

These issues mean that the air weapon magazines must be located early in the design process taking due account of the issues listed above.

It is widely recognised that locating the critical or sensitive spaces of a warship below the waterline means that they are subject to a reduced range of threats. However locating the magazines below the waterline, in effect, as far away as possible from their eventual point of use, brings the considerable problem of weapons movement, stowage and ease of access for removal. Indeed, from a common sense viewpoint it would seem ridiculous to embark stores at the hangar or flight deck, expend a lot of time and effort stowing them neatly deep in the bowels of the ship, for a short time to later get them out of their stores areas and back to the flight deck. But this is exactly the sort of safety problem for an aircraft carrier; the trick is (if the non common sense solution is adopted) to ensure that the weapons stowage and movement issue is as painless as practicable, requiring as little manpower support as possible.

**Design Policies and Tenets**

At the outset of any design, it is vital to be precise on the design policies and standards to be adopted. During the early stages of the design of CVF, Classification Society Naval Ship Rules were still themselves being developed, and thus the design standards for CVF were a mixture of Naval Ship Rules and Defence Standards. The design is now founded upon Naval Ship Rules with a minimum number of Defence Standards.
For the overall configuration of the design, it is important to be clear on a survivability policy encompassing susceptibility, vulnerability and recoverability, as this will dictate overall arrangement, systems routing, shock standard and self defence capability.

In addition to this it is important to set a few simple design tenets at the outset of a design which frame the thinking of the more detailed work to follow. For the CVF design team, these were (in simple terms):

- Design for buildability - in particular routing of cables and pipes, rationalisation and simplicity of structure, zonal commonality and autonomy, adequate space;
- Design for support - ease of removal, ease of access for maintenance, commonality of equipments, ease of ship husbandry;
- Design for aesthetics - both external and internal, reduce clutter, respect passageway widths;
- Have a healthy respect for the operators of both the ship and the CAG, this will improve the design and facilitate acceptance.

THE BASELINE DESIGNS

The Original Competition Winning Design (ALPA)

ALPHA was designed for 40 aircraft (surge up to 50), with a typical sortie generation profile of 150 per day. The deliberations and issues discussed in Section 3 resulted in a 73,000 tonne conventional carrier comprising 10 decks, 19 watertight subdivisions, 2 large deck edge lifts and the unique twin island arrangement. A profile view of the design is provided in Figure 5.

![Profile View of the Arrangement of ALPA](image)

The principal features of the design are as follows:

- 2 x deck edge lifts;
• Through hangar sized to accommodate 26 aircraft plus gallery deck;
• Complement of 1593 (632 CAG);
• All cabin philosophy ~ mixture of 4, 2 and 1 berth cabins;
• Twin galleys plus local refreshment areas;
• Integrated electric propulsion:
  • 11 KV;
  • 4 x propulsion pods.
• 4 x MT30 gas turbine alternators;
• Lloyds Naval Ship Rules for structure;
• Fully automated weapons handling system;
• 3 x deep aviation stores complexes;
• Semi automated provisions pallet handling system;
• Bow thrusters;
• Flight deck crane and dedicated vehicle ramp;
• Many fabrication features to reduce cost.

The ship is arranged in 5 citadels (with the hangar clean until dirty) and 6 damage control zones. The zoning was arranged to achieve as much autonomy in each zone as practicable to aid both the survivability of the vessel and support the 'superblock' build strategy. The bulkhead spacing is dictated by both spatial and stability requirements \(^3\) with the V lines proving a particularly onerous driver on the design. The hangar is 3 decks high throughout its length.

Power is provided by 4 x MT30 gas turbine driven alternators providing about 160MW of power at a sensible power density. The adoption of IEP gave the flexibility to locate the prime movers away from the propulsion train and thus 2 of the MT30s are located in the sponsons.

Considerable work was carried out to technically de risk the propulsion pods to make them as survivable as practicable. The pods were selected because they:

  • Provide additional useable volume within the hull;

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\(^3\) Defence Standard 02-109, Stability Standards for Surface Ships Part 1, Issue 04 2000

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• De risk the build strategy, removing the propulsion train from the critical path;

• Had some hydrodynamic advantages.

The design was to achieve at least 150 sorties per day for a finite period. This together with the Alpha strike requirement dictated the size of the flight deck, the arrangement of the major items on it and also the supporting infrastructure in terms of the numbers and locations of personnel, equipment and stores. As an example, the locations of the aircraft servicing positions within the catwalks are a consequence of the required sortie profile. The CV flight deck arrangement is provided in Figure 6.

FIG. 6 – ALPHA DESIGN CV FLIGHT DECK ARRANGEMENT

Complement (and the need to keep it to a minimum) was a key driver from the start. This resulted in the provision of as much automation as practicable (the machinery spaces are designated unmanned) and specifically the adoption of the Automated Weapons Handling system incorporating dedicated weapons preparation areas. An all cabin configuration was a User requirement at the start of the design process and there are many design features to improve crew quality of life on board. Partly based on the author’s own personal experience, there are no cabins located immediately beneath the flight deck.

The design incorporates 2 x pairs of retractable fin stabilisers and a fully compensated tank arrangement for all variables to avoid stability restrictions and maintain optimum ship motions throughout the vessel’s life.

Buildability was considered from the start of the design, in particular:

• Maximum repeatability and simple construction for structural sections:

  • Minimum numbers of different steel grades, thicknesses, and stiffener types.

  • Maximum deck to deck height to ease system routing (and meet habitability requirements);

  • Provide dedicated pipe and cable passageways, pipe tunnels and use vertical service and personnel routes;
Maximise repeatability of common arrangements e.g. cabin flats;

Equipment arrangement taking due consideration of system requirements e.g. switchboards located with due regard to the simplest route for cabling;

Group associated equipments to maximise opportunities for modularity.

Most of the design features (if not all equipments) from the ALPHA design can be seen in the QE Class detailed arrangements.

The Minimum Viable Technical Design (Bravo)

By mid 2003, it was recognised by the Alliance that the full capability of ALPHA would be too costly for the UK, and it was thus decided to produce a minimum viable technical design which, it was anticipated, would also result in minimum cost.

For BRAVO, the aircraft number was reduced to 34 (with the ability to surge to 40) and the required sortie profile cut to typically 110 sorties/day. Drawing on past flight deck studies, it was considered that an overall length of about 265m was the minimum to sensibly operate the required number of aircraft. The reduction in sortie profile and hangar stowage requirements had associated impacts upon the volumetric and deck area requirements which resulted in a reduction in the total number of decks from 10 to 9. The resulting design arrangement is provided in Figure 7.

The principal modifications from the ALPHA design are provided below:

- Complement of 1450 (608 CAG):
  - Reduced standard of accommodation.

- Single galley complex;

- Power generation:
  - 2 x MT30 gas turbine alternators;
  - 2 x 12.6MW diesel generators;

Fig.7 – BRAVO PROFILE VIEW

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• Shaft driven, 2 x fixed pitch propellers;
• Semi automated weapons handling system;
• 2 x deep aviation stores complexes;
• Conventional stores pallet handling system;
• No bow thrusters, flight deck crane or dedicated vehicle ramp;
• Reduced survivability.

As the design of BRAVO matured it became increasingly apparent that this minimum viable design, whilst meeting cost constraints, was having difficulties delivering the capabilities required by the client, in particular with regard to: power generation, available deck area, and in the interpretation of the stability requirements 3. By the end of 2003, it was agreed that BRAVO needed to be modified to increase its capability and initially this was confined to the addition of 5 extra transverse bulkheads within the main hull to meet stability aspirations. This resulted in design CHARLIE as shown in Figure 8.

![FIG.8 – CHARLIE DESIGN](image)

Whilst this met stability aspirations it did not solve the issues associated with power generation capability and deck area requirements, and it was thus decided to increase the primary dimensions. This increase resulted in the DELTA design ~ the final configuration currently under construction at various shipyards in the UK. This design is briefly described (where security constraints dictate) in the following section.

**DELTA DESIGN DESCRIPTION**

The CV Adaptable carrier is a 9 deck ship with an overall length of 280 metres, an overall beam of 70 metres and a depth to the flight deck of 29 metres. The ship has a zonal architecture providing autonomy in various segments of the ship as well as allowing cross connection of systems in the event of system failure or damage. The ship will displace approximately 65,000 tonnes at the start of life. Figure 9 provides a profile view.

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The ship is designed around 34 aircraft comprising Joint Strike Fighter fixed wing aircraft and Merlin helicopters and has the ability to surge up to 40 aircraft for short periods of time.

The hangar has an overall volume of 29,000 metres$^3$ which can accommodate about 20 x JSFs in a nested configuration. The flight deck area is over 13,000 meters$^2$ with a runway leading to a single ramp or ski jump. There are 6 landing spots. The flight deck is characterised by the twin island arrangement which was adopted for survivability, spatial, and sensor separation reasons. The bridge is located in the forward island with FLYCO aft, but both functionalities are interchangeable to some degree. There are two large deck edge aircraft lifts for transit of aircraft between the hangar and flight deck.

Being a CV Adaptable carrier, the gallery deck (the deck immediately below the flight deck) contains provision for the inclusion of launch and recovery equipment at some later date. An integrated electric propulsion philosophy has been adopted with the primary power for the ship being provided by Rolls Royce Marine Trent gas turbine driven alternators and 4 large diesel generators. The ship is propelled by 2 shafts each driven by a pair of Converteam advanced induction motors.

The ship’s staff of approximately 1500 (including flight staff) are all accommodated in cabins, with a maximum normal occupancy of 6 to a cabin. Figure 10 provides a view of a typical cabin.
The junior ratings have dedicated recreation areas on each accommodation flat whilst the senior ratings and officers have single integrated areas. There are two main galleys, one for officers and senior ratings and the other for junior ratings. The galleys are serviced by food provisions stores located in the decks below with access provided by food lifts direct to breakout areas adjacent to the galleys. In addition, there is an aircrew refreshment bar in the gallery deck for use by the flight deck personnel during high intensity flight operations.

CONCLUDING COMMENTS
The CV Adaptable Aircraft Carrier discussed in this brief paper represents the culmination of a considerable design effort by an Integrated Design Team. The principal features which describe the design are:

- Large flexible flight deck, carefully designed for aircraft traffic flow;
- Large flexible hangar deck;
- IEP with twin shafts for optimum power management and hydrodynamics;
- Zonal architecture for systems linked to superblock boundaries;
- Cost effective vulnerability features;
- Automation wherever practicable, particularly of weapons systems and stores;
- Environmentally friendly;
- Modular accommodation;
- Designed for buildability;
- Designed for easy reconfigurability to the CV role.

Security constraints have unfortunately precluded the inclusion of many of the specific design features incorporated into the design, but it is hoped that there is enough in this paper, especially in the early sections, to provide some good insight into the carrier design process.

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