

ARCHIVED REPORT

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Queen Elizabeth Class

Outlook

- HMS *Queen Elizabeth* achieved Full Operational Capability in 2021
- HMS *Prince of Wales* achieved Full Operational Capability in 2023
- No additional ship construction expected
- This report will be archived next year

Orientation

Description. Aircraft carrier program tasked with fleet air defense, maritime strike, and sea control.

Sponsor

Ministry of Defence (Procurement Executive)
CB/Admin 3
St. Georges Ct
14 New Oxford St
London WC1A 1EJ
U.K.

Status. Two in full operational.

Total Produced. Two ships commissioned with both in Full Operational Capability at this time.

Application. This carrier class is tasked with offensive air operations against shore targets and fleet roles that support power projection requirements.

Pennant List

<u>Name</u>	<u>Builder</u>	<u>Laid Down</u>	<u>Launch Date</u>	<u>Commission Date</u>
R08 <i>Queen Elizabeth</i>	BAE Systems	7/7/2009	10/7/2014	12/7/2017 (a)
R09 <i>Prince of Wales</i>	BAE Systems	5/26/2011	12/21/2017	12/10/2019 (b)

(a) Full combat operational service in 2021.

(b) Full combat operational service in 2023.

Price Range. The original cost projections by the U.K. Ministry of Defence suggested that the total funding for the two CV(F) carriers was to be \$3.2 billion, putting the unit cost at \$1.6 billion. This did not include the air group or some research and development funding for the onboard systems, which

increased the unit cost to between \$2.0 billion and \$2.4 billion.

By the end of 2019, with the HMS *Prince of Wales* commissioned, the total program cost was reported to be GBP7.6 billion, which equaled \$9.8 billion – or roughly \$4.9 billion per carrier.

Queen Elizabeth Class**Contractors****Prime**

BAE Systems, Maritime	http://www.baesystems.com/en/our-company/our-businesses/maritime , Bldg 20X , PO Box 5, Filton, Bristol, United Kingdom, Tel: + 44 117 918 8284, Email: futurecarrier@baesystems.com , Prime
Babcock International Group	http://www.babcockinternational.com , 2 Cavendish Sq , London, United Kingdom, Tel: + 44 20 7291 5000, Fax: + 44 20 7291 5055, Consortium Member
HII Newport News Shipbuilding	http://hii.com/ , 4101 Washington Ave, Newport News, VA 23607-2770 United States, Tel: + 1 (757) 380-2000, Email: nnwebmaster@ngc.com , Consortium Member
Rapco Fleet Support Inc	http://www.rfsbrakes.com , 465 Cardinal Ln, Hartland, WI 53029 United States, Tel: + 1 (262) 367-6210, Fax: + 1 (262) 367-6219, Email: info@rapco-rfs.com , Consortium Member
Rolls-Royce Defence Aerospace	http://www.rolls-royce.com/defence , PO Box 3, Gipsy Patch Ln, Filton, Bristol, United Kingdom, Tel: + 44 117 97 91234, Fax: + 44 117 97 98005, Consortium Member
Thales	http://www.thalesgroup.com , Tour Carpe Diem, 31 Pl des Corolles, CS 20001, Paris, La Defense Cedex, France, Tel: + 33 1 57 77 80 00, Fax: + 33 1 57 77 86 59, Second Prime
VT Group plc	http://vtgdefense.com , Woolston Shipyard, Victoria Rd, Woolston, Southampton, United Kingdom, Consortium Member

Subcontractor

AMS Systems Engineering Ltd	http://www.aircraft-recovery.co.uk , Unit 3, Bentley Industrial Center, Bentley, Farnham, Surrey, United Kingdom, Tel: + 44 1420 23777, Fax: + 44 1420 23900, Email: sales@aircraft-recovery.co.uk (Elevator)
BAE Systems plc	http://www.baesystems.com , 6 Carlton Gardens, Stirling Sq, London, United Kingdom, Tel: + 44 1252 373232, Fax: + 44 1252 383991 (Command System)
DXC Enterprise Services	http://dxc.com , 5400 Legacy Dr, Plano, TX 75024 United States, Tel: + 1 (972) 604-6000 (Three Dimensional Design & Mfg Software)
Imtech Marine & Industry	http://pon.com , Sluisjesdijk 155, Rotterdam, Netherlands, Tel: + 31 10 487 1911, Fax: + 31 10 487 1702 (Internal Equipment)
Lockheed Martin Rotary and Mission Systems	http://www.lockheedmartin.com , 199 Borton Landing Rd, PO Box 1027, Moorestown, NJ 08057-0927 United States, Tel: + 1 (856) 722-4100 (C4I Systems)
QinetiQ Ltd	http://www.qinetiq.com , Cody Technology Park, Ively Rd, Farnborough, Hampshire, United Kingdom, Tel: + 44 0 8700 100 942 (Design Modeling)
Varivane Industries Ltd	http://www.varivane.com , William Rd, Nursteed Industrial Estate, Devizes, Wiltshire, United Kingdom, Tel: + 44 1380 723624, Fax: + 44 1380 728367 (Furniture)

Contractors are invited to submit updated information to Editor, International Contractors, Forecast International, 75 Glen Road, Suite 302, Sandy Hook, CT 06482, USA; rich.pettibone@forecast1.com

Queen Elizabeth Class**Technical Data**

	<u>Metric</u>	<u>U.S.</u>
Dimensions		
Length (overall)	284 m	932 ft
Length (waterline)	263.5 m	865 ft
Beam (extreme)	69 m	226 ft
Beam (waterline)	39 m	128 ft
Draft (max)	11 m	36 ft
Displacement		
Light		55,000 tons
Full load		65,000 tons
Performance		
Speed (max)		26.5 kt
Speed (cruise)		18 kt
Range		10,000 nm @15 kt
Crew		
Ship		1,400
Air group		700
	<u>Type</u>	<u>Quantity</u>
Armament		
Guns		
ILMS	Mk 116 RAM	4
CIWS	Mk 15 Phalanx (20mm)	3
Air group (max)		
Fighter/attack	F-35B	30
ASW helicopter	Merlin HMA.1	6
AEW helicopter	MASC	4
Electronics		
Radars		
Long-range air search	Type 1046 (S-1850 Smartello)	1
Target designation/FCS	BAE Systems Artisan	1
Navigation	Type 1008	2
Electronic warfare		
ESM	Outfit UAT derivative (?)	1
Decoys	Outfit DLH	4
Torpedo decoy	Type 2170 (SLQ-25A)	2
Combat systems		
Command system	BAE Systems CMS	1
Datalinks	Link 14, Link 16 JTIDS and Link 22	
Machinery		
Configuration	Integrated Full Electric Propulsion (IFEP)	
Gas turbines	Rolls-Royce MT30	2x 36 MW
Alternators		2x 31 MW
Electric motors	Alstom Advanced Induction	2x 30 MW
Shafts		2

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Design Features. From a very early stage, the CV(F) design reflected the strong influence of Adm. Sir Michael Boyce, past First Sea Lord, and past chief of the Defence Staff, who promoted the philosophy, "Air is free, and steel is cheap." In other words, hull size and volume are comparatively inexpensive when viewed in the context of the total cost of the ship.

Undoubtedly, a large ship ensures plenty of flexibility for midlife update and expansion, and, in an emergency, the carrier could carry a much larger "surge" air group than normal. The large size also provides the greatest possible deck area, which not only facilitates aircraft handling but also allows the incorporation of large magazines and fuel stowage. The U.K. Royal Navy had demonstrated to the Treasury that a large ship is not only cheaper to build in terms of cost per tonne, but also has lower maintenance costs. However, the larger hull sizes created some operational and support problems – for example, a lack of suitable dry docks – which proved expensive to resolve.

Although BAE Systems was selected as the preferred prime contractor for the CV(F) program, the final CV(F) design was based on that of the losing Thales Naval team. A key factor favoring the Thales design appears to have been recognition of the operational and damage control advantages of Thales' twin-island configuration. This provides a physical separation of key ship (forward island) and flying control (aft island) functions and, it is claimed, reduces air turbulence over the flight deck. It also allows widely separated engine rooms while wasting less internal volume on trunking to funnels.

The advantages of the all-pod propulsion system used by the Thales design compared well with the less risky hybrid (shaft and pods) system proposed by BAE. According to BAE Systems, the Thales CV(F) design was only a design concept, which it would use as a high-level starting point for the final carrier design; for example, many of the mission systems were quickly changed to those preferred by BAE Systems. In addition, the pod solution for the machinery was discarded and replaced by conventional shafts.

During 2002, the growth in the size of the CV(F) design made the new Rolls-Royce Marine Trent MT30 more suitable to the evolving design than the WR21. Due to its significantly greater power output (36 MW compared with 25 MW), fewer engines are needed to achieve the required generating power. Indeed, despite being 45 percent more powerful than the WR21, the MT30 unit actually requires less volume and is lighter than the WR21 when the latter's complex intercooled, and recuperating system is included. Later experience was to show that the WR21 was troublesome and that the shift to the MT30 had been timely.

The two large, high-capacity (two F-35s) elevators of the Thales design were favored over the three small (a single F-35) elevators of the BAE design, particularly as one of the latter emerged awkwardly in the midst of the island structure. This design augmented the advantages of the Thales design's larger and higher hangar. Although the BAE design was "stealthier" than the Thales design, this was not considered of great importance for an aircraft carrier that displaced more than 60,000 tonnes.

The MoD's September 2002 decision to select the short takeoff and vertical landing (STOVL) variant of the F-35 fighter as the U.K.'s Joint Combat Aircraft (JCA) dictated the final design be a STOVL version of the Thales conventional takeoff and landing (CTOL) design. This saw the ship reconfigured with a bow ski-jump and (allegedly) fitted "for but not with" catapults and arrestor gear. The qualification there is due to the British 2010 defense review that determined *Prince of Wales* should be modified to enter service with catapults and arrestor wires. Plans then envisioned *Queen Elizabeth II* entering service in the original STOVL configuration, albeit without any fixed-wing aircraft, and being placed in extended readiness (i.e., reserve) when *Prince of Wales* entered service. This design change proved to be excessively expensive, and the decision was reversed.

The final design envisioned the installation of both a close-in weapon system (CIWS) such as the Mk 15 Phalanx and an inner layer missile system (ILMS) mount such as Sea RAM. The original design may also have had space and weight reserved for two 16-cell vertical launch silos for ASTER missiles. These provisions were casualties of repeated cost-cutting exercises, and self-defense provisions were reduced to a maximum of three CIWS guns.

For reasons of simplicity and cost, the designers also employed some conventions that have been tried and tested in commercial shipping. For example, previous naval hulls have been of a lightweight construction – those that give the "starved horse" effect. This characteristic is produced when the relatively thin hull plating bows around the closely spaced ribs of the ship. Although this hull design is of minimal weight, it produces a relatively flexible structure that is resistant to shock loads. However, it is difficult to build. CV(F) has a structural design that relies on heavier plating and hull stiffeners that are wider apart. The ship also has a simple hull form, again taken from the world of commercial shipping. Warship hull lines are usually curved to improve speed, and they include many areas of double curvature. The CV(F) carriers, however, have a large section of parallel middle body that makes the associated block easier to construct and assemble.

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Massive sponsons under the flight deck overhangs allow a large hangar space to be incorporated and provide a righting buoyancy when immersed during an extreme roll, or in a severe list caused by hull flooding. Finally, two side-by-side launch positions are provided amidships for F-35B fighters; these allow an extended centerline takeoff run for heavily loaded aircraft. In addition, there are two vertical landing grids for F-35B fighters on the port-side aft.

The stated tonnage was quite low for the probable dimensions when compared to older generations of aircraft carriers that have served in the U.K. Royal Navy and elsewhere. This is due to the lighter weight of many modern systems, components, and materials, as well as an effort to adhere to cost-effective commercial hull construction standards in keeping with new Lloyd's Naval Ship Rules.

Early British aircraft carriers, up to and including the WWII Indefatigable class, carried a substantial weight of armor due to the belief that their relatively small air groups would not provide full defense against attack. This philosophy was discarded with the Invincible class, which did not include a significant amount of armor. The Queen Elizabeth class goes some way toward reverting to the earlier philosophy. Some critical spaces, such as the Operations Room, receive armor (steel or composite) protection at levels determined by vulnerability studies. Since the 20,000-tonne Invincible class vessels were designed in the early 1970s, these studies took major changes in the nature of threats into account. At that time, it seemed almost pointless to try to provide structural defense against Soviet-style heavyweight torpedoes and missiles likely to be encountered in the North Atlantic. The best expected outcome was for a ship to stay afloat after a hit – assuming it had not been hit by weapons with nuclear warheads.

Changes in the threat profile mean that the Queen Elizabeth class will face more diverse threats than the Invincible class. For example, it would be extremely embarrassing if a small craft approached a CV(F) in harbor and was able to disable it with well-placed rocket-propelled grenades and light cannon fire. Actual protection details are classified, but it does appear that the Queen Elizabeth class has extensive internal protection.

Operational Characteristics. A driving force behind the whole CV(F) program is the desire to obtain a much larger air group of considerably more capable aircraft than is possible with the preceding Invincible class. The original requirement was that the adopted CV(F) design be able to accommodate a permanent air group of up to 40 aircraft and be able to temporarily accept an additional 10 support aircraft for a total of up

to 50 in "surge" conditions. In 2002, this requirement was adjusted to a maximum of 48 aircraft and helicopters, and in 2003 to a maximum of 46 aircraft and helicopters. The CV(F) was also originally required to be able to sustain up to 150 sorties every 24 hours, for a cycle of about 12 sorties every two hours. By late 2002, however, the figure had been reduced slightly to 110 JCA sorties (plus support sorties) every 24 hours.

Under current plans, a typical embarked Tactical Air Group (TAG) will consist of one or two squadrons, each carrying 12 F-35B fighters from the (mainly) U.K. Royal Navy-manned Joint Air Wing; a squadron of six Merlin ASW helicopters; and a flight of four Maritime Airborne Surveillance and Control (MASC) aircraft/helicopters. It seems likely that in practice, one or two additional utility helicopters will be embarked on the carrier for sea-air rescue and plane guard duties, carrier onboard delivery, and vertical replenishment (VERTREP). In emergencies, a third F-35 squadron with 12 more aircraft could be embarked, or the two standard squadrons might be supplemented with other squadrons or reserves.

Normally, the large hangar space will be adequate to accommodate all aircraft, considerably aiding serviceability in hostile environments such as the North Atlantic; however, the embarkation of additional aircraft during a crisis would necessitate the use of a permanent flight deck park. It should be noted that operational experience has demonstrated that U.K. Royal Navy objections to permanent deck parks are greatly overstated and tend to be disregarded when needs demand.

To keep costs down, the MoD did not originally require that the CV(F) design have "flagship" standard facilities (command, control, communications, computers, intelligence, surveillance, and reconnaissance – C4ISR) to provide a group command capability. The original plan was that these facilities would be provided by an accompanying Type 45 destroyer or even Albion class LPDs. This reflected prior experience, especially from World War II, that suggested aircraft carriers were a bad flagship choice because they were the center of attention of any attack. In addition, the maneuvering required to operate aircraft was detrimental to group command and control.

However, these opinions were revised when the suitability of CV(F) in terms of space and accommodation for a flag role became obvious. Despite the excellent facilities built into Type 45 destroyers, it became apparent that these ships would have difficulty coping with an air attack and that a higher command level was required. This meant that the new carrier would have to have a fully enabled command and

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control center from which personnel could direct operations on land and at sea.

Another key operational requirement was the need to fit into the U.S. military command infrastructure. To this end, several additional systems were originally required in 2003, the most important (and expensive) being the U.K. Royal Navy's Lockheed Martin-developed variant of the U.S. Navy's Cooperative Engagement Capability (CEC) sensor data distribution and plot fusion system. The sheer cost of the command system as specified was a major contributor to the cost overruns that later caused problems in the program and resulted in the removal of some of the added systems.

Crew levels have been the subject of intense operational analysis. Initial crew targets were extremely optimistic when the contractors were encouraged to aim for a crew of about 600, plus air group personnel. It was therefore hoped that the normal peacetime "lean-manned" CV(F) crew complement (including air group) would be similar to that of the Invincible class. This, however, seemed improbable from the start, although it was admitted that the larger air group on the CV(F) would require more personnel to run it. Further increases would result from the modified command and control requirements that would involve embarkation of a command staff (normally Commander U.K. Naval Force) or a Joint Force Headquarters Afloat.

In order to reach the target crew size, the original CV(F) design automated as large a proportion of the heavily manned systems as possible. However, in mid-2003, the CV(F) Integrated Project Team (IPT) and Future Carrier Alliance re-evaluated the cost-effectiveness of some of these automated tech systems. For example, in the late 2002 design, the weapons-handling role was almost entirely automated and required only 20 weapons handlers, compared with the 250 of a USN Nimitz class carrier.

As a result, the cost vs capability trade-off process saw many of these automated systems being deleted. According to Naval Architect/CV(F) Simon Knight (BMT Defence Services), "There will certainly be automation in some form. In the past evolution, the magazine was fully automated. The preparation of the weapon was also semi-automated. We will now look at what is manpower-intensive and what a robot could best do." By late 2005, the likely crew size had crept up from 600 to nearly 1,400, with an even larger increase in air group numbers.

The plan was for crew accommodation on the new Thales-designed carriers to exceed the high standards adopted for the new Type 45 destroyers. Instead of "traditional" large mess decks, junior rates would have four-berth cabins; senior rates, two-berth cabins; and

officers, shared or individual cabins. The accommodation and hotel facilities were designed in the expectation that about 10 percent of the ship's crew will be female.

The goal was for the ship to have considerable excess accommodation, although mostly to a more austere standard than for the crew and air group. At one stage, the accommodation was sized for as many as 2,000, but it has since shrunk drastically owing to the likely reduction in hull size and the expected slight increase in air group size, as well as for cost savings. This accommodation could be used for an embarked military detachment (e.g., a company of Royal Marines, complete with supporting weapons and equipment) or for the conduct of sea training classes for RNR or BRNC midshipmen, for example. It could also serve humanitarian purposes (e.g., accommodating evacuees and refugees). A small hospital with comprehensive medical facilities is included.

The CV(F) was originally designed for a service life of 30 years (the same as the Invincible class), but the IPT's target is now 50 years. In this context, the large size of the CV(F) carriers is a major problem. The full-load displacement of 64,000 tons and a 950-foot length makes it difficult for the carriers to routinely and safely enter and berth at either of the U.K. Royal Navy's main two bases – Portsmouth Naval Base and Devonport Naval Base. Maintenance is also made more difficult, as there is no suitable dry dock for a Queen Elizabeth class carrier at either location. Of the two major bases, Devonport has only the No. 10 dock, which is restricted to ships of about 40,000 tonnes and 850 feet in length. Portsmouth is even worse off, with its two largest docks (C and D) slightly smaller than No. 10. Lengthening any of these docks, or constructing a new dry dock, would be a budget-breaking exercise.

On July 2, 2002, it was announced that the new carriers would be based at Portsmouth. As part of a major redevelopment effort, Portsmouth had received new jetties suitable for berthing CV(F)s. However, it was confirmed that if the new carriers exceeded 45,000 tonnes – which they already did – they would have problems entering or exiting the base except on unusually high tides. Also, Portsmouth has a narrow entrance channel, where the two carriers could not pass each other. Adm. Sir Alan West, First Sea Lord and chief of Naval Staff at the time, said that dredging would be needed to get the new carriers into their home base.

As a result of these considerations, a massive scheme to enhance Portsmouth Naval Base was announced in July 2003. The plan, estimated to cost between GBP150 million and GBP200 million, included dredging a deeper and possibly new approach channel to

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Portsmouth, dredging the main channel inside the harbor, and refurbishing several of the base's jetties. This process would ease access and provide support for the new aircraft carriers and the new Type 45 destroyers. New facilities would include carrier mooring off Stokes Bay; an upgrade of naval base infrastructure, including buildings, parking lots, and roads; and improved access to the base's largest basin, No. 3.

Although it should be possible to berth two Queen Elizabeth class carriers in Portsmouth simultaneously,

for military reasons this may not be desirable. Options are therefore being considered to make use of an occasional standby berth for the high state of readiness *Queen Elizabeth* that is not subject to the arrival and departure restrictions in place at Portsmouth Naval Base.

During HMS *Queen Elizabeth's* visit to New York in October 2018, the Royal Navy revealed that the ship is fitted with a traditional English "Public House" bar serving a craft ale brewed especially for the ship. The bar is open to officers and senior enlisted personnel.

Variants/Upgrades

Queen Elizabeth II. This carrier has been completed to the original design with a ski-jump forward and no arrestor gear. Plans have been abandoned for a modernization that would have reduced her to extended readiness status in 2020; under this modernization, the ski-jump would have been removed and replaced by catapults and arrestor gear. The original plan was for her to alternate with *Prince of Wales* in service, retaining the possibility of both carriers deploying as a surge capability. This has also been abandoned.

Prince of Wales. Plans to modify *Prince of Wales* while under construction (with catapults and arrestor wires in place of the ski-jump) have been reversed.

PA2 French Second Carrier. Since the inauguration of the CV(F) program, France showed interest in aligning its aircraft carrier program with the CV(F). The serious deficiencies of the *Charles de Gaulle* have led to suggestions that the second French carrier should be a modified version of the CV(F). The French inclination to turn the CV(F) program into a multinational venture has been firmly rebuffed by the British, who have bitter memories of the problems experienced with the CNGF Horizon program. The British position was that if the French wish to order a CV(F), they may do so, but the ship's design and specification will remain a U.K. Royal Navy responsibility. Perhaps not coincidentally, the French interest ebbed quickly from that point.

Subsequently, Thales proposed to build a CTOL version of its CV(F) design for the French Navy. This would displace about 65,000 tonnes full load. In competition, DCN proposed a stretched *Charles de Gaulle* displacing about 50,000 tonnes and able to carry 50 rather than 40 aircraft, with four rather than two catapults, and with four rather than two K-15 reactors, for a maximum speed of 34 knots (an extraordinarily high speed, even with four reactors).

By 2005, the French version of the CV(F) design had been dubbed "Project Juliette" in France and CV(F)-FR

in the U.K. France's modifications for its own requirements would be minor, centering on:

- Internal redistribution of the aircraft bays in the hangar
- The command and control systems needed for a command ship – the French carrier would be able to embark 100 command personnel, making it a headquarters for an amphibious expeditionary force
- The combat management system – the U.K. probably would use a system compatible with its Type 45 destroyer, while France likely would opt for one that works with its FREMM multimission frigate
- The layout of the CV(F) flight deck – the French Navy wanted changes to allow for the installation of catapults and arrestor gear, based on their experience launching and landing Super Etendard and Rafale fighters on the nuclear-powered *Charles de Gaulle* carrier
- Other French Navy design changes – storage capacity for jet fuel will be increased to 5 million liters from an initial 3 million, reflecting experience with the Rafale

In the event that an agreement was not reached between the French and British governments, the French Navy had a fallback plan designated "Project Romeo." This was essentially an enlarged and modified version of the *Charles de Gaulle*, using conventional rather than nuclear propulsion. Major planned improvements included increased tonnage, greater margins for meeting future requirements (e.g., UAVs), an ability to operate heavier aircraft (due to the longer catapults), a larger hangar, a bigger and higher flight deck, improved ammunition stores and preparation areas, adaptable aviation fuel tanks, and aviation workshops and stores adequate to support a similar-sized air group for longer deployments. Many of these improvements were based

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on lessons learned from the deployment of *Charles de Gaulle* in Operation Heracles in 2001-2002.

After the signing of the joint development Memorandum of Understanding (MoU) in March 2006, the small French team at the offices of the Aircraft Carrier Team in Bristol quickly built up to more than 20 personnel and began comparing the requirements of the Marine Nationale for PA2 with the British studies for the CV(F). The objective was to enable the French PA2 Prime Contract Office (MOPA2) to identify what could be transferred directly from the U.K.'s work, what had to be adopted or modified, and what needed to be replaced, developed, or added for PA2. The MOPA2 also studied no fewer than three CTOL deck layouts and revised hangar arrangements to accommodate larger maintenance facilities.

The French DGA (Defense Procurement Agency) was looking for detailed industry proposals for a PA2 based on the CV(F) design in expectation of placing the order by the end of 2006. A key factor was cost. However, according to the French 2008 Defense White Paper,

overall defense spending through 2020 would comprise an estimated EUR377 billion (\$581 billion), or about \$48.4 billion annually (note: this figure does not include pensions). Defense expenditure as a percentage of GDP would decrease from the current 2.3 percent to annual allocations of 2 percent. A key point in these economies was that the government decided to postpone a decision on whether to proceed with the project for a second aircraft carrier until 2012. At that time, the decision was made to cancel PA2.

In October 2018, the French Navy commissioned an 18-month study budgeted at EUR40 million to determine the feasibility of a future replacement of the French aircraft carrier *Charles de Gaulle*. If this study suggests that a replacement is economically and technically feasible, the proposed timeline places the decision to proceed after 2025, with the new carrier being ordered after 2030. The future carrier is to have a service life of 50 years, meaning it will remain in service until beyond 2080. It is unlikely that any proposed design emerging from this initiative will have anything more than a superficial resemblance to the Queen Elizabeth class.



Queen Elizabeth Fitting Out

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Program Review

Background. The long, drawn-out process of designing a replacement for the U.K. Royal Navy's three air-capable Invincible class ships was initiated in 1991. By 1992, the conceptual form of the CVHG(R) had evolved into an enlarged and simplified version of the Invincible. A key decision at this early stage was that the Sea Harrier airframe would not be further developed and that the U.K. would buy into the U.S. Advanced

Short Takeoff and Vertical Landing (ASTOVL) program. This led to the U.K. funding 20 percent of ASTOVL, and announcing its plan to increase its share to 35 percent if necessary. This decision marked a major increase in the striking power of the ship. As a result, the designation was changed from CVHG(R), which implied an ASW orientation, to CVSG(R), with the S standing for strike.

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On July 7, 1993, the U.K. MoD released a Request for Proposals for a combat system concept design (CSCD) study for the Invincible replacement. Effectively a prefeasibility study, it examined the levels of technology required for the command system and associated weapons and sensors. This was followed in September 1994 by an Invitation to Tender (ITT) for the prefeasibility-phase concept definition study for CVSG(R), the results of which would be used to formulate a staff target.

CVSG(R) Confirmed

In January 1995, an impending ITT for a two-year prefeasibility design support contract was announced. This was to be followed by concept formulation and a project definition phase. The 1998 Strategic Defence Review more or less laid the foundation for the U.K. Royal Navy's procurement plans, including the CVSG(R) program. The number of ships was confirmed to be two, each weighing 35,000 to 40,000 tonnes. This major increase in size reflected a further expansion of the ship's capabilities, which was also reflected in another change in designation, this time to CV(F), standing for Future Aircraft Carrier. This study also benchmarked a rough timetable for the project, with an estimated launch of the first ship in 2010, followed by sea trials. The initial target date for entry to service was 2012. The second ship was expected to be operational by about 2015. At the same time, the parallel ASTOVL program was planned to produce an operational aircraft for service in 2012.

In October 1998, at the Euronaval exhibition in Paris, the French Defense Ministry began to express concerted interest in cooperating with Britain on the development of a new aircraft carrier. The idea would be to explore the potential for a standardized design on a number of major systems and subsystems. The size of the CV(F), as stated in the Strategic Defence Review, was to be about 40,000 tonnes, similar to the French Charles de Gaulle class. The U.K. Royal Navy explicitly ruled out nuclear propulsion, and was predisposed to a Joint Strike Fighter (JSF) capable of short takeoff and vertical landing (STOVL) as the carrier's primary aircraft. The French, in contrast, were committed to conventional takeoff and landing (CTOL) aircraft, which require a different flight deck design. However, France suggested that the nuclear propulsion of the *Charles de Gaulle* did not necessarily have to be duplicated in a possible follow-on version.

CV(F) Arrives

By the spring of 1999, the size of the CV(F)-class ships was reported to have increased to 40,000-50,000 tonnes. The basis for these reports was the old rule of thumb that an aircraft carrier needed 1,000 tonnes of

displacement per aircraft carried. The maximum capacity of 50 aircraft would, therefore, require an aircraft carrier weighing 50,000 tonnes. Also, experience of operations in the Adriatic showed that, while the Invincible class could carry a significantly larger air group than originally envisioned, they had undersized munitions storage and aircraft maintenance facilities.

By late 1999, the various consortium rivals for the CV(F) program were forming. Rolls-Royce and Harland & Wolff joined BAE Systems to compete with a second team comprising Thomson-CSF (now Thales), Raytheon, and BMT Defence Services. Lockheed Martin joined the Thomson-CSF group in February 2000. In December 1999, the two consortia received \$10 million Analysis of Options contracts encompassing cost/capability/program tradeoffs, risk analysis, and concept development.

Growing Importance

Despite the importance of CV(F), the high cost of the project inevitably generated criticism, and the terrorist attacks of September 11, 2001, likely played a key role in saving it from cancellation. The success of the USN's carriers in Afghanistan, and the associated limitations of the much smaller HMS *Illustrious* in the same action, greatly reinforced the government's commitment to CV(F).

On November 22, 2001, the MoD awarded BAE Systems and Thales Naval Ltd competing 12-month contracts worth around GBP30 million each for AP2. Revised and shortened compared to the original plans, AP2 (Risk Reduction and Cost Capability Trades) ran over six phases lasting until November 20, 2002, and involved work to develop parameters for the detail design, build, and support of the preferred carrier option. The work outputs were to provide the basis for the choice of a prime contractor by the MoD.

Design Work Gets Real

On November 20, 2002, AP2 was completed with the submission of the last deliverables. The CV(F) IPT completed its evaluation work at the beginning of December, with its report showing that the Thales proposal was technically and financially superior to the BAE proposal in a number of areas. The MoD's Investment Approvals Board (IAB) discussed the report at its meeting in December and at two additional meetings in January, finally endorsing a recommendation that the prime contract go to Thales – the growing possibility that the French Navy would then order a third unit, which would help cut costs, perhaps being an additional inducement. The MoD's preference for Thales leaked to the press in late January and

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unleashed considerable controversy, with the carrier program becoming one of the most politically charged defense contracts of recent years. This may have impacted the decision to appoint BAE Systems as prime contractor.

More Design Studies

AP3 was completed by March 2004, by which time the Joint Carrier Alliance had delivered to the MoD a "robust, fully costed proposal" for the demonstration and manufacture of the two vessels of either 50,000 or 60,000 tonnes full load. BAE Systems, as the preferred prime contractor, was required to ensure the maximum degree of competition among potential subcontractors in order to obtain the best proposal price. Thales hoped to get about one-third of the work as a key subcontractor, but BAE Systems said that this was far from guaranteed. A significant change from contemporary British defense contracts was that the MoD agreed to bear up to 10 percent of any cost overruns.

Another bombshell was dropped in June 2003 when BAE Systems warned the Ministry of Defence that it could not build the CV(F)s to budget, and that it now estimated a cost of GBP3.8 billion (\$6.2 billion) in the Demonstration and Manufacture phase to construct the pair – a full GBP1 billion above the available budget. BAE Systems officials blamed the U.K. Royal Navy's continual adding of requirements to the CV(F) project in part for the cost escalation. The nature of the disclosure, which suggested that BAE Systems had significantly marked up its costs since receiving the prime contractorship in January 2003, angered some industry officials. They claimed to have consistently advised the Defence Procurement Agency (DPA) that two vessels meeting all the criteria laid out in the user requirements document could not be built for the GBP2.8 billion earmarked for the D&M phase. During the summer of 2003, the MoD considered several options for the CV(F) project:

1. Two large adaptable carriers. This implied continuing with the current 60,000+ tonne design, but subjecting it to a ruthless cost-benefit analysis, removing nonessential features and capabilities without reducing the size.
2. Two smaller "optimized" carriers. To further reduce costs and try to stay within budget, the CV(F) design would be shrunk to the minimum practical size (about 50,000 tonnes displacement) needed to retain "adaptability" and still meet most other key requirements.
3. Two smaller STOVL-only carriers of 40,000 to 45,000 tonnes displacement. The future-proofing "adaptability" would be dropped to allow a further

reduction in size and cost. This was effectively a final fallback option.

4. One large adaptable carrier. Just one large "adaptable" carrier would be ordered, and greater coordination would be sought with the French to help fill the gaps when the carrier was not available.

The affordability of options 1 and 2 would be considerably helped by a French contribution toward the development costs if the design were to be selected for their new carrier requirement, PA2. Option 4 was quickly ruled out by the U.K. Royal Navy and the MoD. And any move to shrink the ships (options 2 and 3) would reduce their effectiveness and ability to project power around the world. However, full RAF support for both the CV(F) concept and the use of RAF aircraft and personnel for naval operations became crucial if option 1 was to be viable – it would be pointless for the U.K. Royal Navy to make great sacrifices to build two large carriers if there were no planes available to operate from them, and this support was not forthcoming. During August/September 2003, a decision was apparently made in favor of option 2.

Although this "midsize" CV(F) design was by far the favorite option, the DPA failed to make a firm decision to go with it despite intense pressure from BAE Systems for a decision at the beginning of 2004. The U.K. MoD also wanted good cost estimates for the big (295 m) and small (260 m) CV(F) variants so that it could do a cost-benefit analysis of the three options before it made a final decision on which design variant to select in 2007.

Enter the French

Related to these events were the ongoing French evaluations of proposals to provide a second aircraft carrier to supplement the existing CVN *Charles de Gaulle*. As might be expected, there was substantial pressure to build a second CVN that would be a virtual repeat of the earlier ship. However, the *Charles de Gaulle* was already regarded as somewhat less than satisfactory, and an alternative, conventionally powered option was pushed. Primarily promoted by Thales, this drew heavily on the CV(F) proposal made to the U.K. After much debate, the logic of the Thales proposal won the day, and in February 2004 it was announced that the second French carrier would be conventionally powered and be designed by a Thales/DCN consortium.

Originally, the Thales proposal saw the second French carrier, PA2, as the CTOL derivative of the company's CV(F) proposal. However, at the 2004 Euronaval exhibition, a model of the proposed PA2 revealed considerable evolution in design. How much

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commonality remained between the PA2 and CV(F) was (and remained) unclear.

Also in 2004, the names of the two British ships were revealed. As it is a tradition for the first capital ship launched in the reign of a monarch to be named for that monarch, the lead ship was named HMS *Queen Elizabeth*. She also honors a battleship that fought in both World War I and World War II. The second ship was named HMS *Prince of Wales*, a long-standing British capital ship name last used for a King George V class battleship that participated in the sinking of the German battleship *Bismarck*. She was subsequently sent to Singapore, where she was sunk by Japanese air attack.

During 2005, the basic design of the Queen Elizabeth class was revised and refined within the context of a "100 days" review. The configuration of the hull changed significantly, gaining approximately 8 meters in length, but with the sponsons reduced in both width and volume. During this period, the emphasis was placed on finally completing agreements for the Carrier Alliance, and for the (inevitably) BAE-led consortium that will build the ships. The window of opportunity for France to join the CV(F) project was rapidly closing if timescales were not to be negatively affected.

Two options for French involvement were being considered: either licensing the CV(F) design to France so that it could build a third carrier or letting France join the project and participate in building all three carriers. There were fears that the latter option would delay the U.K. program. A French decision was originally due by the end of September 2005. On October 18, 2005, however, the Commons Defence Select Committee heard that France had put off a decision on whether to join the U.K. program until December. French thinking appeared to be that the two-month delay would be used to arrive at a more detailed assessment of potential cost savings, a sign that France was taking the prospect of joining the U.K. program more seriously.

On December 12, 2005, DCN and Thales France revealed that a tailored version of CV(F) would be developed for France's new aircraft carrier. They announced that they had been awarded a contract to develop a design concept based on the CV(F) as France's next aircraft carrier (Porte Avions No. 2 – PA2). At a meeting between U.K. Defence Minister John Reid and French Defense Minister Madame Michele Alliot-Marie on January 24, 2006, considerable progress was made in resolving some cooperation issues.

An internal review of the CV(F)-FR design was completed on June 22, 2006. This noted how the British CV(F) design could be adapted to meet the

needs of the French Navy and be included for purposes of a first financial estimate. It was suggested that contracts for further detail design work and the procurement of long-lead items could be placed by the end of 2006, with an actual order for the ship now deferred to the end of 2007. The long-lead equipment was to include U.S.-manufactured steam catapults and arresting gear. First steel was to have been cut in 2009, with a 2015 in-service date.

Exit the French

In 2008, after many months of anticipation, French President Nicolas Sarkozy revealed that his government's new white paper outlined France's defense policy approach for the next 12 years. The new White Paper on Defense (Livre Blanc sur la Défense) was the first crafted by the French government since 1994. Since that time, much had changed, including wholesale alterations in the military forces of Europe, as well as the strategic threats facing France. Although the government was keen to emphasize the increase to the annual equipment budget, it postponed a decision on whether to proceed with the project for a second aircraft carrier until 2012 at the earliest.

This decision was essentially a death sentence for the idea of PA2 being a French version of the Queen Elizabeth class. The first indication of the delay was that the PA2 would be unable to replace the *Charles de Gaulle* during its 2015-16 refit and refueling. By late 2012, no decisions appeared to have been made, although the original PA2 design had been significantly refined. Recent changes included a redesign of the ship's underwater lines to streamline the hull, and a reduction in the size of the propulsion plant.

Another indication of the four-year hold on PA2 was that the French Navy had re-evaluated the case for nuclear propulsion for its new aircraft carrier, a decision also driven by the soaring cost of fossil fuel. The latter, in particular, made very attractive the concept of an all-new design that retained the nuclear powerplant of the *Charles de Gaulle* with a much-enlarged hull that avoided the defects of the earlier design. Proceeding with this option in 2012 would allow construction to start in 2017-18 and the carrier to enter service in 2025, by which time *Charles de Gaulle* would be almost 30 years old. This made it obvious that PA2 was now being conceived as a replacement for the *Charles de Gaulle* rather than a companion. In other words, the "second French carrier" proposal had been de facto canceled. This interpretation of events was confirmed in the April 2013 Defense and Security White Paper, which stated that France would not pursue plans for a second aircraft carrier. In 2018, the French Navy started studies into a replacement for the *Charles de Gaulle*, but

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any connection of this proposal to the Queen Elizabeth class is likely to be ephemeral at best.

Back to the U.K.

As of December 2005, the apparent target date for the second part of the Main Gate – approval for the actual manufacture of the ships – was December 2006. It was recognized that the original in-service dates of 2012 and 2015 could no longer be achieved. On April 13, 2006, the CV(F) Demonstration Phase Alliance Agreement and individual work contracts were signed by the MoD and its five Aircraft Carrier Alliance (ACA) partners – BAE Systems, KBR, Thales UK, VT Group, and Babcock. The legally binding agreement established the alliance management arrangements and relationships.

It appears that the entire Queen Elizabeth class program went through a significant crisis in early to mid-2007. During that period, there were increasing fears in British naval circles that the new carriers would be canceled as part of an upcoming defense expenditure review. News had surfaced in December 2006 that the MoD was conducting a rapid review of its equipment spending priorities – a review in which the U.K. Royal Navy seemed to be the likely loser in favor of the Army.

The Nightmare Scenario?

By January 2007, British newspapers were filled with reports that further deep cuts were planned for the U.K. Royal Navy, with reports publicly suggesting that the Queen Elizabeth class would be canceled. These reports were strongly rebutted by both the MoD and senior government officials. Lord Drayson told the House of Lords on January 18, 2007, "I have made clear to the Aircraft Carrier Alliance that time is now critical. I am looking to get a robust, affordable deal negotiated quickly to allow a main investment decision to be taken as soon as possible. Consider the rumors quashed."

It therefore was a great relief when, four years later than once expected, the British government finally gave the U.K. Royal Navy approval to order two new aircraft carriers of the Queen Elizabeth class.

As part of this announcement, it was revealed that there had also been discussions concerning the air group for the British carriers. Originally, the proposal was to build the two British carriers as STOVL ships with a ski-jump bow. There was much speculation that only the first carrier would be built this way, with the second being completed as a CTOL carrier. The first ship would then be modernized to CTOL configuration at an early refit. This unusual procedure was described as an attempt to bridge the gap between the availability of the first carrier and the delivery of the F-35s ordered by the British.

The statement that confirmed the order for the Queen Elizabeth class also indicated that the U.K. Royal Navy's plans to buy 60 Future Carrier Borne Aircraft (FCBA) had been subsumed into the RAF-dominated Joint Combat Aircraft (JCA) program – with the RAF originally wanting 90 aircraft. The MoD's equipment plan at that time slipped the aircraft's entry into service from 2014 to 2017 (it was originally 2012). This meant that the new carriers would be limited to carrying Harrier GR.9s for strike operations until at least 2018 and probably 2019.

It was believed that the U.K. would order, at most, 80 carrier-capable F-35B Joint Strike Fighters for both land- and carrier-based JCA operations, perhaps equipping four frontline squadrons with nine aircraft each – two of these squadrons hopefully forming the Naval Strike Wing by the end of the next decade. This idea added weight to the suggestion that the Queen Elizabeth class was switching from a STOVL to a CTOL configuration.

A final part of the announcement was that an alternative-build strategy was being devised, with the aim of saving time during the assembly program and thus making up for some of the delays that had plagued the project. The previously announced allocation of the modular "super blocks" to the alliance shipyards remained (hull lower Block 4 at BAE Systems Govan, Block 3 at BAE Systems Barrow, Block 2 at VT Group Portsmouth, and the bow [lower Block 1] at Babcock Rosyth, where assembly would take place), but the assembly sequence would be reversed, with the stern (Block 4) entering the dock first. Babcock would undertake the upper blocks above Block 4, and the size of the upper blocks would be reduced by building the "super blocks" higher, removing the need for investment in a "Goliath" crane at Rosyth. Substantial elements of the ship structure were competed and competition within the super block subcontract maximized, expanding overall competition to around 60 percent of the work.

Even at this point, there were last-minute efforts to derail the Queen Elizabeth class program, with Army and Air Force officers lobbying intensively for its cancellation. However, these efforts failed, and on July 7, 2008, the U.K. MoD finally signed the contracts for construction of the Queen Elizabeth class aircraft carriers. These contracts authorized work worth GBP1.325 billion for construction of the super-modules of both ships by BVT Surface Fleet at Govan on the Clyde and at Portsmouth; GBP300 million for construction of the super-modules of the ships at the BAE Systems yard at Barrow-in-Furness; GBP675 million for construction of the bow section and for final assembly and completion of the ships by

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Babcock Marine, with assembly taking place at Rosyth; GBP425 million for design and engineering by Thales UK; and GBP275 million for the design and supply of mission systems by BAE Systems Integrated Systems Technologies (Insyte).

Problems and delays with the Queen Elizabeth class did not cease at this point. The primary cause of the uncertainty over the class remained the financing. The British defense budget as then constituted was already inadequate to support the burdens placed upon it when the 2008 international financial crisis broke. This caused the British government to increase spending as part of a "stimulus package," then to contemplate major spending cuts to bring the financial deficit under control. Given the political preferences of the Labour Party, it was considered likely that the inevitable funding cuts would fall primarily on the defense budget. Some press speculation put the size of the cuts as high as 25 percent. One option discussed in late 2009 was to complete only HMS *Queen Elizabeth* as an aircraft carrier. HMS *Prince of Wales* would then be completed to a much-simplified standard for service as an LPH to replace HMS *Ocean*. This meant that the dedicated replacement for HMS *Ocean* would be abandoned. As part of this scheme, British purchases of the F-35 would be slashed to 50 aircraft.

Change of Plans

In the British 2010 general election, the Labour Party was removed from power and replaced by a coalition of the Conservative Party and the Liberal Democrats. One of the first acts of the new government was to call for a new Strategic Defence and Security Review (SDSR) that would supersede the previous review that dated back to 1998. This review would take into account the government's massive deficit as well as the large number of unfunded liabilities that were present in existing defense planning. These two requirements alone ensured that the defense review would have made severe cuts to defense expenditure.

Almost from the first days of the review process, it became apparent that the Queen Elizabeth class aircraft carriers were in danger of cancellation. The Royal Air Force was, as usual, implacably opposed to any U.K. Royal Navy fixed-wing aviation program, while the Army saw cancellation of the carriers as the best way to fund the equipment and operational costs it was accumulating in Afghanistan. Combined with the political segments that saw any cancellations of defense programs as desirable in and of themselves, a powerful anti-carrier coalition had formed at the beginning of the defense review.

The earliest manifestation of this coalition's strategy was a suggestion by the RAF's Chief of Staff,

Sir Glenn Torpy, that up to GBP1 billion could be saved in the short term by phasing out the Harrier strike aircraft and standing down the Joint Force Harrier. Coincidentally, this would also destroy the carrier program by eliminating the vertical short takeoff and landing (VSTOL) aircraft that the existing carrier design made essential. This met with a strongly negative reaction from the U.K. Royal Navy, and from that point on, the armed services were conflicted. The situation was not eased by the revelation that the cost of the two carriers had increased by over GBP1 billion.

In view of these circumstances and the Treasury insistence on deep cuts in government expenditure, it was generally assumed that at least one, and possibly both, carriers would be canceled in the defense review. This was not so, although the British prime minister described them as being the result of all the wrong decisions. Both aircraft carriers survived, although the second, *Prince of Wales*, was to be delayed by two years in order to modify her for aircraft operations using catapults and arrestor wires. The plan was that, once *Prince of Wales* was commissioned, *Queen Elizabeth* would be placed in extended reserve and modified to the same standards. Thereafter, the two carriers would alternate in service, although the Navy could retain the ability to surge both into service if needed. Alternatively, one of the carriers could be sold.

During early 2011, rumors spread that the commissioning dates had been pushed back to 2020 for HMS *Queen Elizabeth* and 2023 for HMS *Prince of Wales*. At that time, there was no official confirmation of these timeframes, although subsequently the progress of the ships conformed to this timetable.

After more than a decade in which seemingly every stroke of bad luck that could possibly afflict a navy had struck the U.K. Royal Navy, 2011 saw a change in fortunes. The last of the three light carriers to serve in that role, HMS *Ark Royal*, was decommissioned and gutted for spare parts. Just eight days later, the British government elected to join the NATO air forces in a military intervention on behalf of the anti-al-Qadhafi rebels. By that time, HMS *Ark Royal* was already beyond recommissioning, and the possibility of restoring her to service and giving her an air group of similarly salvaged Harriers had evaporated.

It was painfully apparent that despite the nearly ideal environment for land-based operations, the RAF could not equal the cost-effectiveness or timely response of carrier-based aviation. This point was driven home by Italy, which, flying eight AV-8Bs off the very small amphibious warfare ship *Giuseppe Garibaldi*, managed to contribute more to the international effort than the British. The result was that the anti-carrier position that

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had dominated British press coverage of the program was suddenly and decisively muted. The serious mistakes made in the SDSR became impossible to ignore, and the U.K. Royal Navy's case for retaining both of the new carriers was immensely strengthened.

In May 2012, the extent to which the "black hole" (the financial resources required to complete defense programs that had been initiated but whose completion had not been funded) had reached crisis proportions was finally recognized. This resulted in a further round of defense cuts. Although the Libyan intervention served to protect the carriers from any threat of cancellation, the program was hit by a different threat. It had become apparent that the reorientation of the ships from ski-jump to catapults and wires for aircraft operation was going to be much more expensive than originally thought. In an admission that was embarrassing for the government, it was announced that the plan was being abandoned and that both ships would be completed with ski-jumps as originally planned.

The decision to switch from a ski-jump to catapult configuration and then back again (at a cost of GBP180 million) appears to be based on the claim that the Queen Elizabeth class was "future-proofed" by provision for rapid conversion from one configuration to the other. Such flexibility could well have been present at an early stage in the design, but the window of opportunity for such conversions had passed.

In October 2012, the first eight sailors to join the crew of HMS *Queen Elizabeth* arrived in Rosyth. They started work alongside the Aircraft Carrier Alliance in developing the ship's organization, routines, and procedures. By July 2013, assembly work on the *Queen Elizabeth* was nearing completion. Both islands were in place and the primary hull structure appeared complete. All that remained to be fitted to the ship were two sponsons to support the flight deck extensions and the bow ramp or ski-jump. The final section delivered was the aft island, also known as Upper Block 14. The island operates as an airport control tower and is the center of the ship's flight operations. Housing 110 compartments, the island is over 30 meters tall and contains more than 44,000 meters of cable. The forward island housing the main bridge had already been erected on the flight deck of the ship in Rosyth. Both islands are designed with the ability to incorporate the other's role in an emergency, increasing the ship's survivability.

In July 2014, HMS *Queen Elizabeth* was launched. She was christened by Queen Elizabeth herself on July 4.

After leaving open a final decision on whether or not the U.K. Royal Navy would ultimately get to operate both

of the 65,000-ton aircraft carriers under construction, late in 2014 Britain's Conservative-led coalition government opted in favor of bringing both ships into service. Prime Minister David Cameron previously let it be known that he would put off a final decision on whether to operate both carriers until the next SDSR, due in 2015. However, the decision was brought forward by 12 months. This meant that, from 2020 onward, the U.K. Royal Navy would be able to have a carrier operating at sea on a consistent basis.

In February 2015, RAF 17 Squadron, which is responsible for operational test and evaluation of the U.K.'s first F-35s, was formally stood up at Edwards AFB, California.

Carriers Get into Shape

By May 2016, work on the installation of Sponson 11, the final hull block for HMS *Prince of Wales*, was well in hand. Sponson 11 extends over three decks and contains a variety of compartments, including stores, workshops, a mooring deck, and a planning complex/briefing room. This work occurred at a time when the lead ship of the class, HMS *Queen Elizabeth*, was getting ready to start sea trials. Trials took place on June 26, 2017, when HMS *Queen Elizabeth* set sail from Rosyth for a three-hour initial sea trial that demonstrated the ship's ability to move and maneuver. These trials were monitored by a large number of interested spectators, who tracked the ship's progress on the Internet using her AIS display. Other interested spectators included Russian submarines, ships, and aircraft.

The outcome of the trials was reported to be highly satisfactory, with the *Queen Elizabeth* exceeding specifications in terms of speed, maneuverability, stability, and seakeeping. These initial trials also addressed the ship's hotel facilities, ensuring that she was ready to accommodate a full crew. This initial run was followed by six weeks of more detailed trials in the North Sea, after which she transited down the western coast of the U.K. to take up her new station in Portsmouth, where she arrived on August 16, 2017.

HMS *Queen Elizabeth* set sail again on October 30, 2017, following two months of planned maintenance and defect rectification. In the second phase of builder's trials, she operated a variety of helicopters from her flight deck. These included the Merlin and Chinook helicopters operated by both the Royal Navy and British Army. The flight arrangements of *Queen Elizabeth* proved suitable for the simultaneous operation of multiple aircraft of these large types. The ship was commissioned into the U.K. Royal Navy on December 17, 2017.

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The first F-35Bs operated from HMS *Queen Elizabeth* on October 18, 2018. The trials took place off the East Coast of the United States, with the carrier being escorted by HMS *Monmouth* and USS *Lassen*, a Type 23 frigate and an Arleigh Burke class destroyer, respectively. After completing the F-35B trials, the carrier visited New York before returning to her home base of Portsmouth. During 2019, HMS *Queen Elizabeth* featured in a British "reality" television series. (The series proved popular enough to be taken up for a second season.)

October 2020 saw the deployment of the U.K. Royal Navy's first carrier strike group in over 10 years when a force of nine ships, 15 F-35B aircraft, 11 assorted helicopters, and 3,000 personnel from the U.K., the U.S. and the Netherlands conducted operations in the North Sea. The Royal Navy described the gathering as "the largest and most powerful European-led maritime force in almost 20 years." The carrier strike group included the destroyers HMS *Diamond* and HMS *Defender* and USS *The Sullivans*, with ASW cover provided by the frigates HMS *Northumberland*, HMS *Kent*, and HNLMS *Evertsen*. Logistics support came from Royal Fleet Auxiliary ships RFA *Tideforce* and RFA *Fort Victoria*.

Two Russian Tu-160 long-range bombers attempted to intercept the naval formation but were themselves intercepted by Royal Air Force Typhoon fighters long before they got within strike range of the ships.

UKRN Tests New Missile System for Defense Against Small Boat Attacks

In October 2021, the U.K. Royal Navy successfully tested a new missile system designed to protect the U.K.'s new aircraft carriers from attacks by swarms of small boats.

During operations in the Pacific Ocean with the U.K. Carrier Strike Group, HMS *Defender's* Wildcat helicopter of 815 Naval Air Squadron fired the Martlet lightweight missile at an inflatable target in the sea – known in the Navy as the big red tomato.

This was the first time this type of missile had been launched in frontline operations by the Royal Navy, following rigorous testing at ranges off the U.K. coast by the Yeovilton-based Wildcat Maritime Force.

In 0.3 seconds, the missile detached from the Wildcat HMA Mk 2 helicopter, accelerating to one and a half times the speed of sound toward its target.

The purpose of the missile system is to add another layer of protection around the Royal Navy's aircraft carriers, with the Wildcats able to carry up to 20 of the

laser-sensor missiles that can be used against stationary and moving targets.

Capt. James Blackmore, Carrier Strike Group's Air Wing Commander, said, "Martlet is a new air-to-surface lightweight multirole missile recently introduced into service for the Wildcat helicopter and provides an offensive and defensive capability against small boats and maritime targets that may pose a threat to the Carrier Strike Group.

"The Wildcat is a phenomenally versatile aircraft and the inclusion of up to 20 missiles on each of the four embarked aircraft adds yet another potent capability to the Air Wing and the Carrier Strike Group. This first firing during an operational deployment not only gives confidence in the end-to-end weapon kill chain but also offers an overt demonstration of one of the many strike capabilities provided by the Air Wing from within the task group."

The Martlet missile, available for all Wildcats deployed with the task group, is part of the ring of protective steel around HMS *Queen Elizabeth*. Merlin helicopters and F-35 Lightning stealth fighter jets complete the protective ring.

UKRN Aircraft Carriers Ready for Arctic Operations

The U.K.'s largest warship, the HMS *Prince of Wales*, sailed within 900 miles of the North Pole as the U.K. Royal Navy "pushed the boundaries" of aircraft carrier operations into the Arctic. The carrier led a task group to 77 degrees North in the North Atlantic to demonstrate the ability of the U.K.'s two 65,000-tonne Queen Elizabeth class carriers to operate in the harshest environmental conditions. The ship returned home to Portsmouth on April 20, 2022, after training with allies from NATO and the U.K.-led Joint Expeditionary Force, having "laid the foundations for Royal Navy carrier operations in the High North for the next half century."

The carrier and her task group, including frigate HMS *Richmond*, destroyer HMS *Defender*, tankers RFA *Tiderace* and *Tidesurge* and a hunter-killer submarine, remained in the North Atlantic to continue their Arctic deployment/cold weather operations under the banner of U.K. defense's new policy of contributing to the wider defense of the High North.

HMS Prince of Wales Conducts F-35 Flight Testing

During September 2023, F-35 fighters conducted a third round of developmental flight testing (DT-3) onboard the HMS *Prince of Wales*.

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The tests included employment of the ship-rolling vertical landing capability to enable the fighter to operate in the heavy sea's environment. The carrier conducted flight operations in the English Channel with W Autonomous Systems' fixed-wing UAS to gather information on UAS supply deliveries.

Additionally, MV-22 Osprey aircraft joined testing designed to expand the aircraft's onboard operating limits. The HMS *Prince of Wales* also hosted flight

operations for General Atomics' Mojave medium-altitude, long-endurance UAS.

F-35s first completed flight operations on the HMS *Queen Elizabeth* carrier five years ago and conducted a first Carrier Strike Group (CSG) deployment in 2021. The HMS *Prince of Wales* is expected to embark on its first planned deployment in 2025.

Funding

Development and construction are being funded by the U.K. MoD. In the spring of 1997, a team of researchers at York University estimated that three large carriers would cost GBP3.6 billion. In addition, a fleet of 60 JSFs would add another GBP1.8 billion, meaning that the total cost of the program, including the aircraft, would be more than GBP5 billion. The 1998 Strategic Defence Review (SDR) pegged the cost of the two ships at roughly GBP2 billion, stretched out over a period of 20 years. The cost of the aircraft would range between GBP5 billion and GBP7 billion, depending on the aircraft type selected. The total cost of the carrier program is now put at more than GBP10 billion.

To the above should be added the lifetime maintenance and operating costs, which would be another GBP5 billion. The total would be equal to 2.5 percent of Britain's annual defense budget, or less than the cost of the Trident submarines or the Eurofighter Typhoon aircraft.

The original cost of converting the ships from a ski-jump to catapult configuration was estimated at GBP180 million to GBP200 million. When a detailed analysis of these costs was made, it was determined that the estimates had been slapdash and were wildly optimistic. It also appeared that claims that the ships could be easily converted from one configuration to the other could not be supported. If such flexibility had once existed, it was lost during the detail design process. While the original expectation was that the changes would be restricted to 80 compartments (out of about 1,200), the detail design showed that major modifications to over 290 compartments would be required, with 250 more needing smaller modifications.

An accurate assessment of the cost of converting the second-in-class ship, HMS *Prince of Wales*, had more than doubled, from just under GBP1 billion (\$1.5 billion) to GBP2 billion. The first-of-class ship, *Queen Elizabeth II*, which was more advanced in construction, would need GBP3 billion in modification costs. Modifications for both ships would thus cost GBP5 billion – close to what they had been expected to cost without any. Up to the time that the decision to convert the ships from a ski-jump to catapult configuration was reversed, more than GBP180 million had been spent on the proposal.

Financial issues surfaced again in 2017 when the unsatisfied funding deficits of around GBP250 million per year became a perceived problem. In addition, the Brexit negotiations created an atmosphere of uncertainty around future financial arrangements. There were numerous suggestions that HMS *Prince of Wales* would be put into mothballs immediately on completion, but these rumors were denied. Subsequently, emphasis shifted to making major cuts in the amphibious warfare fleet to help fund the deficit.

Contracts/Orders & Options

No recent contracts publicly identified.

Worldwide Distribution/Inventories

U.K. Two ships of class in service.

Queen Elizabeth Class**Forecast Rationale**

The introduction of the aircraft carrier HMS *Queen Elizabeth* represents a long-overdue reconstitution of the U.K. Royal Navy carrier strike capability. The simple fact that an aircraft carrier with an adequate defensive screen had conducted sea trials in the North Sea demonstrated a major change in the U.K. Royal Navy's operational posture.

In the future, when additional funding becomes available it will likely be spent on additional F-35B aircraft for the carriers. Currently, the force structure adopted for the F-35B fleet consists of a four-squadron fleet of 12 aircraft each. Of these, one would normally be assigned to carrier operations, one to land operations, and two to training and support. A one-carrier surge would see three squadrons deployed to a single carrier,

with a training squadron held in reserve. A two-carrier surge would see two squadrons assigned per carrier, with no reserves. The latter option would permit a larger complement of support aircraft such as ASW helicopters and early warning aircraft.

While both aircraft carriers have technically been commissioned, only HMS *Queen Elizabeth* (commissioned December 7, 2017) has reached full combat fleet operational capability, which was achieved by the end of 2021. HMS *Prince of Wales* (commissioned December 10, 2019) reached full combat fleet operational capability by the end of 2023.

Production of this ship class has been completed thus the forecast chart is omitted. This report will be archived next year.