RN AIRCRAFT CARRIER STUDIES

BY

J.F.P. Eddison, RCNC
(formerly FP211 CV(F) Project in DNA&FP)

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ABSTRACT

The Royal Navy has for some years been undertaking studies for a potential new aircraft carrier, the CV(F). This article provides a brief overview of the progress of these early design studies. It describes the background to the project, outlines the programme, discusses the main design features and then goes on to describe the range of studies carried out so far and some of the results. It concludes by identifying the way ahead for the project, and discussing areas of innovation.

Background

The RN's current aircraft carriers, the Invincible class (Fig. 1), reach the end of their design life from about 2010. The class has been progressively modified to provide a broader range of military capabilities than the original design intent, and the basis of the new requirement is that these capabilities shall continue to be provided, and enhanced where appropriate, in response to the demands of the changing world scene. A new class of aircraft carrier (up to 3 in number), the CV(F), to carry a new class of combat aircraft is emerging as the most cost-effective option to meet the following requirement:

To provide:

- A power projection capability
- Air defence for the fleet
- A Force Command facility.

However, as there is as yet no formal project, the CV(F) must strictly be considered as only one option. Later phases will assess it against alternatives.

Considerable Operational Analysis (OA) is being carried out progressively to support this requirement. Meanwhile the MoD (UK)'s Directorate of Naval Architecture and Future Projects has been developing a range of costed aircraft carrier designs as potential technical solutions to the requirement. Together the OA and the costed solutions will form the basis of a submission for approval to begin Feasibility Studies (FS).

Preliminary indications are that up to 20 fixed wing aircraft may be required to meet the perceived demands of both power projection and air defence, in the most hostile circumstances. A further 10 aircraft (probably but not necessarily rotary wing) may be carried to provide Airborne Early Warning (AEW) and some Anti-Submarine Warfare (ASW) capability.

Programme

The overall programme is working towards confirming the Staff Requirement in 2000/2001, with the first ship being ordered in 2004/5 and Contract Acceptance some 6 years later (Fig. 2). Further ships may be ordered to match the out of service dates of HMS *Illustrious* and *Ark Royal.*

FIG. 1—HMS 'INVINCIBLE'

Because an aircraft carrier is nothing without its aircraft, the whole programme supports and is matched to the programme (FIG. 3) for the Future Carrier Borne Aircraft (FCBA). This is intended to maintain the RN's organic air capability when the SEA HARRIER goes out of service. The currently favoured option for the FCBA is the Short Take-Off Vertical Landing (STOVL) variant being developed by the US Joint Strike Fighter (JSF) programme. This is intended to provide a common basis aircraft, with Service variants, for the USN, USAF and the USMC. The FCBA would be the USMC variant.

The JSF programme is now in the Concept Demonstration phase, having downselected the prime contractors from three to two, Lockheed Martin and Boeing. (McDonnell-Douglas was the unlucky one.) Several UK aerospace companies are subcontractors to both prime contractors, and considerable manoeuvring can be expected in the run-up to the next phase, as they seek to position themselves for a share in the lucrative production work for over 3000 aircraft. This phase will lead to flying demonstrators in 1999/2000 and further down selection in 2001 to a single contractor for Engineering and Manufacturing Development and Initial Production. The UK is contributing to the current phase as a full collaborative partner, and will decide at the turn of the century whether the JSF programme offers the best option for a suitable and affordable solution to the FCBA requirement. The key date is early next century, when there is expected to be a well defined way ahead for the aircraft, and hence for the ship design to match it.

Up to now however, the concept design team has been developing some early ideas on possible designs and costs, looking at new technology and investigating trade-offs. It has also been laying the foundations for the next phase of the programme by opening talks with industry and identifying the more detailed work that will be required.

Design parameters/philosophy

Preliminary studies started in 1992, to:

- Scope the likely range of designs to meet the potential requirement.
- Address areas where the current carriers are seen as unsatisfactory for the roles they now have to perform.
- Introduce innovative ideas where it was seen as sensible to do so, drawing on development work already underway and looking promising.
- Provide information to support later Cost Capability Trade-offs.

Otherwise, there was a conscious decision to make minimum changes in style and systems.

Several broad assumptions were required to get the studies underway.

- The CV(F) is intended to carry a mix of Fixed and Rotary Wing aircraft (FW/RW). The RW is assumed to be MERLIN, though other helicopters may be carried from time to time, up to CHINOOK (or equivalent) size/weight. The possible use of Unmanned Air Vehicles will be considered as an option for Organic AEW and Reconnaissance.
- The FW is assumed to be the JSF STOVL aircraft, which is more demanding of stowage space, deck loading, fuel and weapons compared with the SEA HARRIER.
- The combat system is expected to be biased towards the primary role of operating aircraft ('bird farm'), together with a self defence capability. It is intended that the combat system will entail minimum development and perhaps be a derivative of an existing system, or systems. A Joint Force Headquarters/Commander Task Group (JFHQ/CTG) capability will be examined as an option.
- Top speed might be of the order of 30 knots, with a range of 10,000 nm. and a stores endurance of 60 days. During the pre-feasibility studies, potential advantages were found in the baseline propulsion machinery package comprising an Integrated Full Electric Propulsion arrangement (IFEP), using WR21 ICR Gas Turbines (GT) to supply both propulsion and ship's service electric power through alternators (of which more later). The WR21s are being developed by a joint US/UK programme.

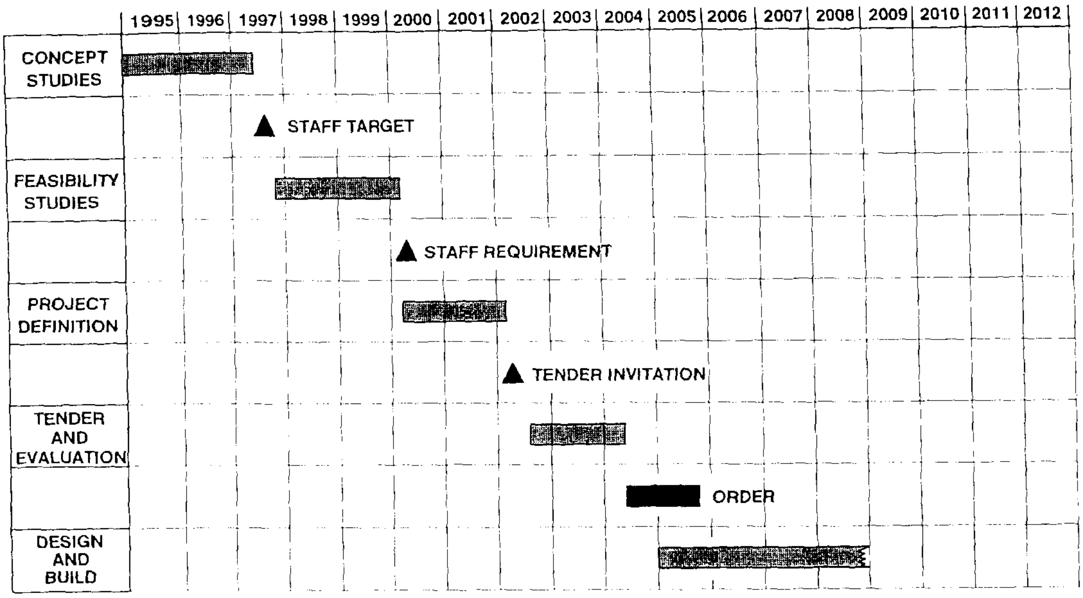

FIG. 2—FUTURE CARRIER PROGRAMME

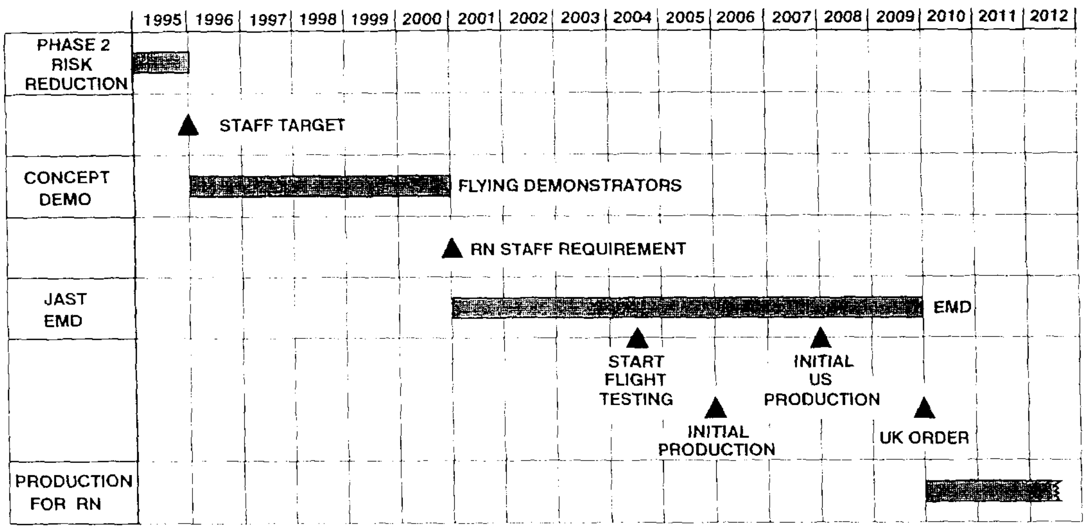

FIG. 3—STOVL JSF FOR FCBA

- The IFEP approach offers the possibility of novel layouts, with space saving benefits, more effective zoning and simplification of equipment fits. A conventional COGAG propulsion system will however be costed also, still using WR21s, and will be used as a comparison in choosing the final propulsion package.
- The complement is expected to be of a similar size to that in the current carriers, about 1150, but considerable effort will be put into reducing it wherever possible, with the focus being on air operations.
- The shortcomings of the *Invincible* class will be rectified as far as possible. Specific points are:
  - Flight deck size and layout
  - Hangar layout
  - Aircraft lift positions
  - Air weapons and AVCAT capacity.
- Signature reduction and vulnerability reduction are areas which have a crucial influence on the survivability of the CV(F) under attack. Several DRA developments have been investigated during pre-feasibility, and will be studied further in Feasibility.
- Last, but certainly not least, the design has to be both cost effective and affordable. Hence individual features impacting on cost, such as the use of military standards and the size of the crew, will be closely scrutinised for cost effective alternatives. It is intended that cost will be treated on a complete life cycle basis and spend to save measures will be implemented where appropriate.

Design options

The key design driver is of course the number of aircraft to be carried. Some 20 FW fighter/attack and 10 support (possibly RW) aircraft are a credible combat capability in most of the scenarios studied. However, this was not known at the start of the studies, so these began by developing a range of new design carriers, for between 15 and 40 aircraft. The broad range of designs developed were:

- STOVL—15, 20 (Fig. 4), 26, 30, 40 aircraft.
- CTOL—26 or 40 aircraft.
- STOBAR—26 aircraft.
- SLEP—20 aircraft.
- STUFT—20 aircraft.
- LPH variants—Investigation of a range of design variants.

It was assumed initially that all aircraft would be hangared for protection from the elements and greater maintainability. It is this which drives the size of the (STOVL) ship, since the resulting upper deck length is more than adequate for landing and take-off requirements.

Initially, a notional constant combat system was defined, A parallel study examined the combat system in some detail but the final decision will be delayed as late as practicable to encompass emerging technologies.

Taking the number of aircraft as above, the combat system and the other parameters described earlier, a range of new design carriers, to full military standards, has been developed. These are based broadly on the Invincible class hull form, layout and outfit. To compare cost and operational effectiveness however, other designs have also been developed, as described below. However, a full COEIA has not yet been carried out, as this is not normally required until the end of Feasibility.

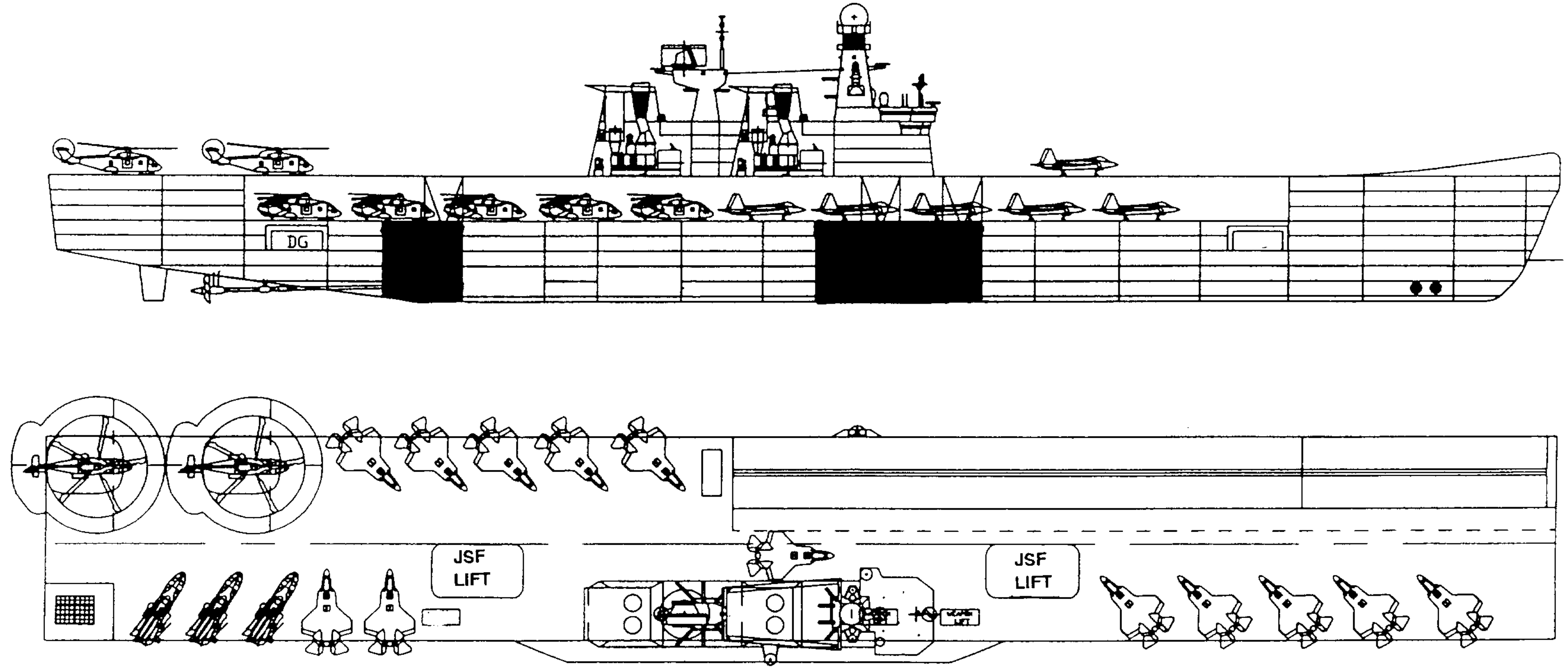

Fig. 4—20 STOVL

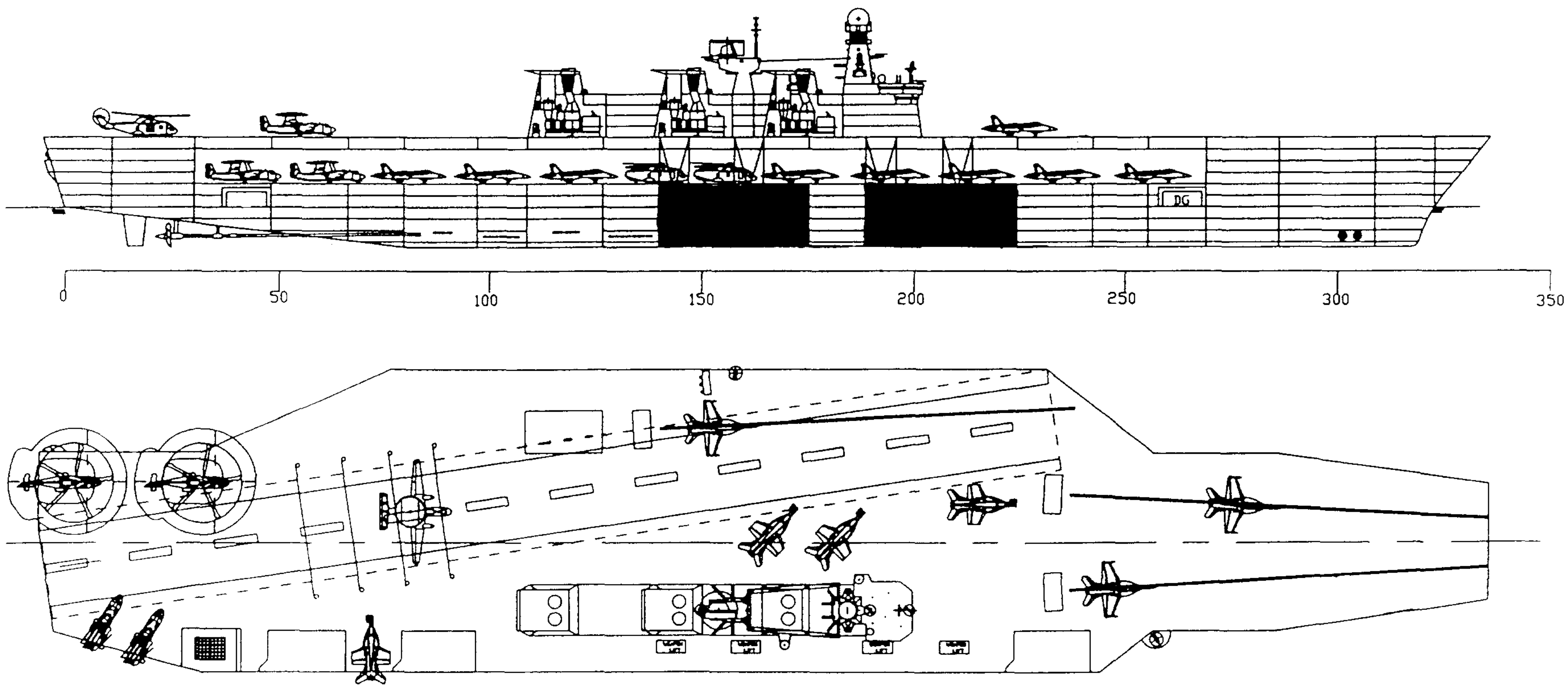

Fig. 5—40 CTOL

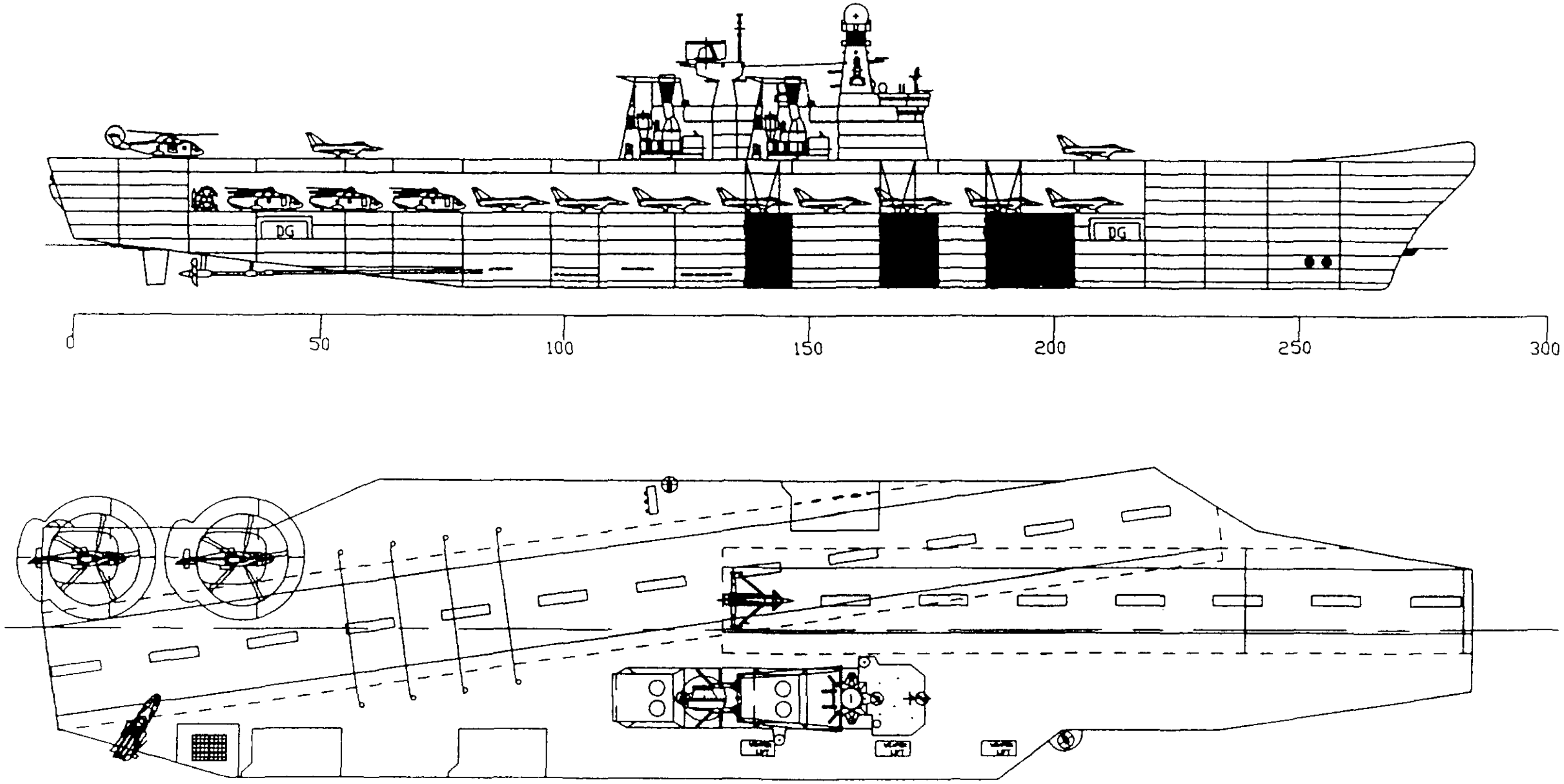

FIG. 6—26 STOBAR

An important alternative to the STOVL JSF variant is a Conventional Take-Off and Landing (CTOL) aircraft, possibly from the JSF programme, or the F/A18 E/F. Hence two CTOL designs, for 26 and 40 aircraft (FIG. 5), have been developed. They are fitted with 2 (or 3) steam catapults, 3/4 arrester wires with fully angled deck, and the separate boilers needed to provide steam in a gas turbine powered ship. Not surprisingly, these equipments have a significant impact on the size of the ship. Even so, the 26 aircraft design is considered about the minimum feasible size for a CTOL carrier.

A further variant is to assume an aircraft, possibly a navalised version of the EF 2000 which can take off without a catapult (but possibly with a ski jump), but which still requires arrester wires. This is the STOAL or Short Take-Off But Arrested Recovery (STOBAR) option (FIG. 6). It is some 5% smaller than the CTOL option, and may involve some limitation of the aircraft payload.

A further range of STOVL designs has also been developed using the design of the LPH, HMS *Ocean*, as a basis. This has involved progressively:

- Reconfiguring the hangar
- Lengthening the design to increase aircraft capacity
- Re-engining to increase speed
- Converting to full military standards.

No small undertaking though fortunately much easier on a Computer Aided Design system than in steel! This work identified, in broad terms, how military standards can be traded against cost, which increased progressively as the design requirements were increased from the comparatively simple and commercial LPH to the full military requirements which might be expected of a front line warship. Interestingly, but to be expected, the cost of the most demanding variant was close to that of the equivalent carrier designed *ab initio* to military standards. These designs will be used to support Cost Capability trade-offs in later stages of the project.

Finally, 2 non-new build options have been examined. A Ship Life Extension Programme (SLEP) for the current carriers investigated what would need to be done to bring them up to the capability required of the new ships and to fit them for a further 30 years of life. A SLEP is ostensibly feasible, at a lower cost than a new build. However, the further costs and risks involved in running the ships on to 60 years old are likely to be considerable, although not yet quantified, and make this an unattractive option technically. In particular, modifying the flight deck to accommodate extra aircraft, while still allowing reasonable ease of flight deck operations, is likely to be almost impossible without extreme alterations.

Second, it is in principle possible to convert a merchant ship to an aircraft carrier. A study was done using a container ship as a basis. This demonstrated that it is possible to obtain an aircraft carrier in this way, but one that falls short, in several important respects, of the requirement. It is also not much cheaper and represents poor value for money.

Further studies

The work just described made up the first phase of the investigations—Concept Exploration. It gave a first approximation to the principal characteristics and cost of the major variants for the CV(F). Concept Studies then examined changes to particular design features and developed data to support trade-offs in such aspects as complement, propulsion and protection. At this stage advances in technology were investigated, supported by the DERA and by a design contractor.

Because the 20 aircraft STOVL design was indicated as a reasonable solution to the emerging requirement, this was taken as the baseline and detailed studies were conducted around it. Significant design aspects that were investigated included:

Aircraft lift position

Deck edge or inboard?

Propulsion

- COGAG configuration, as in *Invincible*, driving through reverse-reduction gearboxes.
- An IFEP option using the Intercooled, Recuperated Gas Turbines being developed as a joint US-UK venture by Westinghouse and Rolls Royce, the WR21. Propulsion motors could be either the large and heavy synchronous type, as used in many cruise ships, or the developmental Permanent Magnet Propulsion Motors. These have a much higher power density than current technology motors so take up much less space. Integrated Full Electric Propulsion is Integrated because propulsion and ship's power come from a common source, and Full because electric power is used for propulsion over the whole speed range, unlike for example the T23 frigate. It dramatically reduces the number of prime movers, and hence the maintenance load and complement. Also, because the engines do not need to be connected directly through a gearbox to propeller shafts, they do not have to be placed in the bottom of the ship, connected to the upper deck by long and space consuming runs of uptake and downtake ducting. Hence it is possible to place the GTs in the superstructure, and save the space lower down that would otherwise be taken by ducting.

Complement

Derived from current CVSG experience, making allowance for the new aircraft and planned Navy wide efficiency measures, with a further allocation for an enhanced air group for high intensity operations. Although not a significant first cost driver, it is a major factor in through life costs, so the project will be looking for opportunities to reduce it, by judicious use of automation, reduction in maintenance requirements etc.

Surge Capacity

Some 30 aircraft might need to be embarked in more demanding scenarios. However, for lower intensity operations, 20 aircraft may be sufficient. The 20 aircraft baseline design has been modified to accommodate a further 10 aircraft. This is called surge capacity, and the requirement is to provide sufficient space on the flight deck to park these extra aircraft, without impairing efficient flying operations. This of course demands more of the flight deck, and the ship size driver now starts to shift from the hangar to the flight deck.

In addition to deck space, greater air weapons and fuel capacity, increased ship's services, and more accommodation will be provided, as noted earlier. This last is however likely to be of a more austere nature than for the rest of the complement.

Results

Preliminary OA results indicate that a 20 STOVL and 26 CTOL are broadly comparable in terms of their ability to achieve numbers of aircraft over a target. This is partly due to the greater launch rate of STOVL aircraft and partly to the need for some CTOL aircraft to be retained as tankers for aircraft coming in to recover with low fuel.

The CTOL design is of course much larger than the 20 STOVL, both in length and in beam, for the angled deck. It is moving into the region where the constraints of build and maintenance facilities have to be considered, and the operational benefits of larger ships have to be weighed against the need to modify existing or create new facilities. This potential problem applies also to some of the larger STOVL options and will be a significant consideration in later discussions with prime contractors.

Discussion

The final design phase of these early studies is now complete. It has built on the initial exploratory designs and included the lessons learnt from individual studies, in order to produce designs which match the key requirements, as far as these have been determined at this stage. Nine design options have been developed:

- 4 for STOVL aircraft
- 3 for CTOL/STOBAR
- 1 SLEP
- 1 STUFT.

Apart from the number of aircraft, all are to a common requirement, including a 50% surge aircraft capacity.

This information provides the basis for potential Prime Contractors to carry out a further design iteration in Feasibility, in which the level of definition is increased, the costs are refined and the risks to the programme identified in more detail.

This programme of work has examined the key aspects of aircraft carrier design, and these are worth describing in a little more detail.

Aircraft numbers
This is fundamental; ship size is roughly proportional to numbers carried, above a minimum value, and for a particular arrangement.

Aircraft type
Number for number, a CTOL carrier is significantly larger than a STOVL carrier. This is because of the need for catapults, arrester gear and a steam supply, all of which bring with them a greater crew size, as well as an angled deck. These features also dictate a minimum practical size for a CTOL carrier, of about 35–40,000 tonnes, although this is also dependent on aircraft type.

Style
Hangar width and hangar height have a considerable impact on overall ship length, which in practice largely dictates cost. There are several major permutations of ship length, beam and depth which can be tried, each with its pros and cons.

Hangar capacity
The preference is to hangar the peacetime aircraft complement. Taken with the main aircraft maintenance workshops, this determines the length of ship, except for a very small carrier (10–12 a/c), since the resulting flight deck is adequate for air operations. It is of course possible to reduce the hangar capacity and park some aircraft on deck as is the US practice. This may require greater flight deck area, depending on the balance between hangar and deck stowage.

Resistance to Damage
The use of side protection systems to minimize damage from both underwater and above water weapons also drive up the size of the ship, although to a large extent the space is already present for other reasons and the protection is a function of the arrangement of the space.

Complement
A significant through life cost driver

Design and Build Standards

Military standards have traditionally been very demanding, because of the specific military features and the need to assure successful operation under combat conditions. Shock protection and the use of more expensive materials for pipe systems are two examples. Collectively military standards have incurred a cost premium, though the amount has always been uncertain. To examine this, a series of designs based on the LPH philosophy was developed. This has shown the potential to save up to 40% of UPC by using almost entirely commercial standards. While this may be too far for a front line warship, it is clear that significant savings are possible.

The other main features of aircraft carrier design naturally contribute to the end product. However, they are to a great extent contained within the volume dictated by the drivers described above, and changes caused by variations within each feature, such as alternative propulsion systems, have a small effect on size overall. They do of course affect the layout, and individually and jointly make the difference between a good and workable arrangement, and one that is less so. It is to a great extent in the handling of these trade-offs that the art of developing a successful carrier design lies. Further, these features will also affect the cost. (FIG. 7) shows how both first and through life costs vary with the number of aircraft hangared.

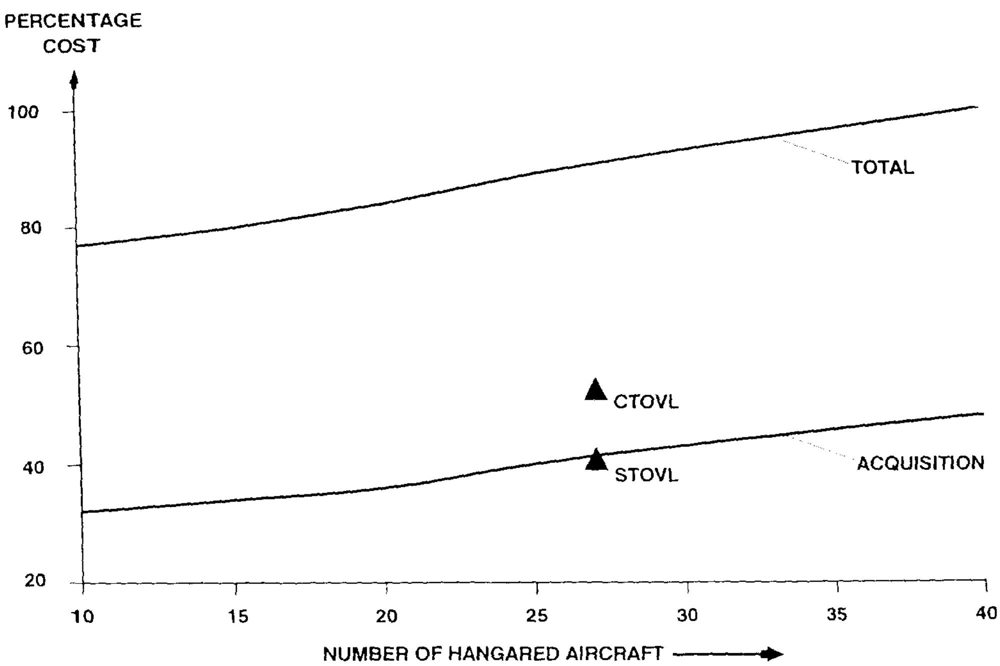

FIG. 7—CARRIER COST V AIRCRAFT NUMBERS

Conclusions

This article has described the extensive programme of work so far carried out by the MoD to prepare the way for approval of a Staff Target and entry into the next phase of the CV(F) project. Once the Staff Target has been approved, the MoD intends to invite bids to carry out parallel feasibility studies.

Finally, an article on an aircraft carrier for the twenty-first century would be incomplete without a summary of those areas where new technology could make an important contribution:

- The new Intercooled and Recuperated WR21 Gas Turbine, which has a diesel's fuel economy, but much greater power density.
- Structural Radar Absorbent Material (SRAM), a composite material which is an option for non primary structure, e.g. the island, sponsons, fittings. It will require different maintenance techniques.
- Integrated Full Electric Propulsion, possibly with Permanent Magnet Propulsion Motors. The possibility of supplying all electrical requirements, for propulsion and ship services, from a common 'power station' has exciting layout advantages for the ship designer, and interesting consequences for the operator/maintainer.
- The aircraft itself, the subject of a parallel development programme.
- The Combat System, again drawing on current development work for other projects and on COTS initiatives through the CSTDF project.
- Complement reduction measures. It is expected that significant effort will be directed to reducing this large portion of the running costs of the CV(F), by greater automation, alternative maintenance policies, low maintenance materials and equipment, IT, etc.
- Vulnerability and signature reduction measures.
- Finally, if the CTOL option is taken up, there are developments in catapult, and possibly arrester gear, technology aimed at removing the cost and complexity of steam.

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