THE IMPACT OF V/STOL ON AIRCRAFT CARRIER DESIGN

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ABSTRACT

There can today be little doubt that the cancellation of projected Attack Carrier CVA-01 in 1966 and the decision to phase out the Royal Navy's seaborne tactical air capability would have had the gravest of consequences during the Falklands crisis, had it not been for the coming together of two significant events in the history of Naval Aviation: the ordering in 1972 of the Through Deck Cruiser, and the persistence of the Royal Navy in pressing home its case for seaborne organic airpower - which resulted in agreement in 1973 to proceed with an RN Harrier programme.

The successful blending of these two developments into what is now known as the Invincible Class of Anti-submarine Carrier has paved the way for the much wider introduction of V/STOL into other navies of the world.

However, it should be remembered that the Invincible Class was not designed 'from the ground up' to take V/STOL, and cannot, therefore, be considered as a true V/STOL Carrier, but as an evolutionary step along the road to V/STOL Naval Aviation, albeit a most significant one.

This Paper deals with the impact which the V/STOL aircraft has had, and will have in the future, on carrier design. By way of illustration, attention is drawn to the part played by the authors' Company (VSEL) in the development and build of HMS Invincible and Class and the unique insight which that involvement provided during the development of the Company's own Private Venture V/STOL carrier designs.

1. INTRODUCTION

1.1 Requirement for Air Capable Ships

For many years now, major maritime powers have realised that the exercise of sea power should be supported by the use of aircraft at sea. Experience has taught that for successful seaborne surface operations, air superiority must be maintained in the operating area. This can be accomplished by the use of land-based aircraft but, as was demonstrated during the Falklands crisis, if operating at large distances from friendly bases seaborne air cover is required.

Whilst it is well known that helicopters can be operated from many different types of vessel, the ability to deploy, simultaneously, more than one kind of aircraft, in sufficient numbers to maintain continuous operations for a sustained period, requires a purpose-built vessel. This is particularly true when fixed-wing aircraft are used in conjunction with large helicopters, such as the Sea King.

Modern aircraft can carry a wide range of weapons and stores, which enables a small mix of these aircraft to perform a wide variety of roles, including:

- reconnaissance and surveillance,
- engagement of sea and land targets,
- engagement of hostile and shadowing aircraft,
- anti-submarine warfare, using large helicopters,
- landing and recovery of ground forces,
- search and rescue, and
- peacetime tasks such as personnel or casualty transport.

In addition, the aircraft carrier, as probably the largest vessel in the task force, is likely to be the Command and Control Centre for the force, requiring extensive C^3 (Command, Control and Communications) equipment.

Thus an air-capable ship is able to provide:

- air cover for the ships of the task force,
- command and control of the task force, and
- support to an amphibious assault.

1.2 Evolution of Aircraft Carriers

The first recorded use of a ship as a platform for the deployment of aircraft was on 14th November 1910, when Eugene B Ely flew a Curtiss biplane from a temporary platform attached to the bows of the American Light Cruiser 'Birmingham'. Two months later he landed a similar plane on a 120 ft platform over the stern of the USS 'Pennsylvania', using a wire and sandbag arrester gear. Both of these flights were carried out with the ships at anchor and used an airfield at one end of the flight.

Unhappy about the large deck area required for take-off, the Americans devised means of saving space by using compressed air to catapult a seaplane from the bows of a ship, and a crane to recover the aircraft after it landed in the sea. The introduction of folding wings in 1913 lead to further saving of space. Similar experiments were carried out by the Royal Navy, with ramps and catapults.

At the outbreak of World War I the advantages of operating aircraft with the fleet, principally for observation and reconnaissance, were realised. This prompted the Admiralty to rapidly commission the conversion of a number of merchant vessels to sea-plane carriers. These vessels were equipped with large hangars and aircraft handling cranes, but had no flight decks. The first purpose-built seaplane carrier for the Royal Navy was the Ark Royal, launched in 1914. These vessels saw action at the Dardanelles, where their seaplanes were used as spotter aircraft during bombardment, and were able to sink a Turkish merchant vessel using torpedoes. Also, observations from the seaplanes of HMS Engadine were instrumental in bringing about the Battle of Jutland in June 1916.

Despite these successes, the poor performance of seaplanes when compared to wheeled aircraft, and the requirement of calm water for seaplane operations led to the development of vessels capable of the launch and recovery of wheeled aircraft. The world's first flush-decked Aircraft Carrier, HMS Argus, converted from a merchant liner, was commissioned just too late to see action in the First World War.

Between the wars, the major navies of the world began building Aircraft Carriers in significant numbers and which evolved into the conventional Aircraft Carrier form with a flat through-deck and island superstructure to starboard.

The desire to operate monoplanes before and during the Second World War led to the adoption of catapults on the forward part of the flight deck. As the speed of aircraft increased during the Second World War, so the advantages of bigger ships with longer flight decks became clear. Thus the Ark Royal of 1938 displaced 22,000 tonnes on an overall length of 244 metres, while the Eagle of 1952 displaced 44,000 tonnes on 247 metres overall length (Figure 1).

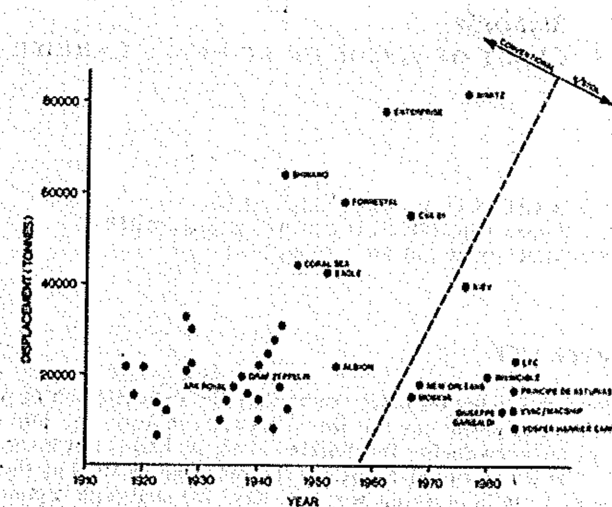

Figure 1 Variation of Carrier Displacement with Date

The advent of the jet aircraft in the late 1940s and early 50s would probably have signalled another step increase of size, had it not been for three British developments.

> First, the angled flight deck, whereby the landing aircraft, should it fail to catch an arrester wire, is able to take off again over the port bow and come round for another try. The angled flight deck also enables a larger 'deck park' to be used without the risk of an aircraft, having missed the arrester wires, ploughing into the parked aircraft.
>
> Second, the steam catapult, which is capable of imparting a much greater velocity to the aircraft than the previous hydraulic, pneumatic, or cordite propelled catapults, and finally,
>
> mirror landing sights and audible air speed indicators to aid the pilot in making his approach.

Even so, the proliferation of the aircraft carrier's roles, plus the desire to be able to carry a greater number of higher performance aircraft, has led to larger, more complex, and thus, more expensive, Aircraft Carriers.

2. CAPABILITIES OF V/STOL AIRCRAFT

2.1 Comparison of VTO-STO Performance

The arrival in service of the vectored thrust jet V/STOL fighter, the Harrier, followed by the Sea Harrier, brought about a new concept in aircraft-carrying ships.

It is now possible for almost any ship with a flight deck to deploy these aircraft in the VTO/VL mode. As was shown by the emergency landing of a Sea Harrier on the Spanish Merchant Ship Alraigo in June 1983, all that is required to land a Harrier is a flat area of about 7m radius, clear of any obstruction. Thus it is possible for almost any vessel in the fleet to have a fixed-wing jet aircraft capability.

However, as stated by Fozard [1] the disposable load that may be lifted by the Sea Harrier in VTO mode, is limited by engine thrust to 2,200 kg. This represents about half the aircraft's maximum disposable load - a remarkable achievement.

In short take off (STO) mode, the Harrier's wings produce an additional 9 kg net lift for every metre of run [2]. So to lift the maximum disposable load of 4,500 kg would require an STO of at least 260m. On land, in still air, the requirement to not only lift the payload but also to accelerate it in an upwards trajectory requires a clear STO Strip of some 360m. The height above sea level of a ship's flight deck, and the lack of obstructions in the sea, allows the aircraft to leave the deck in level flight. In addition, Fozard [2] has shown that the deck run on a ship may be reduced by 3.3m for every knot of wind over deck. Thus with a 25 knot wind over deck, a Sea Harrier may lift its maximum 4,500 kg load from a deck run of 180m.

The foregoing figures show that for the most cost-effective operation of V/STOL Aircraft, to use their maximum range and military load, requires a ship with a through-deck, rather than a half-deck ship of the Moskva type.

2.2 Ski-Ramp

In 1973, Taylor [3] proposed the idea of using a ramp at the forward end of an Aircraft Carrier's flight deck to impart an upward momentum to the aircraft on take-off. The aircraft is then launched at sub-stall airspeed, accelerating while it follows a part-ballistic trajectory, to achieve level flight by the time it has descended to approximately flight deck height; nozzles are then rotated aft to achieve fully wing-supported flight.

In theory, this approach could be applied to any type of aircraft, but the sub-stall controllability of the Harrier-type aircraft, together with its ability to augment wing lift with thrust, makes this the only practicable choice.

Owing to the adverse effect on pilot morale of having negative rates of climb at low altitude, shortly after take-off, the trajectory now aimed for on a ski-ramp take-off is one that is always climbing, but with a point of inflection.

Thus, the inclusion of a ski-ramp creates the possibility of either increasing the payload carried by the aircraft on an STO of given length, or reducing the required deck run for a given payload. In addition, the ski-ramp improves operability in rough seas, since the initial trajectory is always upwards, even in significant bow-down pitch, and improves safety, giving the pilot more time to eject in the unlikely event that thrust is lost at take-off.

To-date, ski-ramps have been generally of circular arc profile, and successful launch has been achieved at ramp exit angles up to 20 degrees on land, 12 degrees at sea. The minimum radius of curvature of the ramp is limited by the reactions on the aircraft undercarriage, due to centripetal acceleration. A ramp of 20 degrees exit angle and 150m radius of curvature would need to be some 50m long and extend to a height of nearly 9m.

From a Naval Architectural point of view, although a shallow ski-ramp may be an advantage, giving a pleasing sheer forward, and reducing deck wetness, a structure of the dimensions given above would cause difficulties with regard to the view from the bridge, arcs of fire of weapon systems, turbulence on the flight deck and ship handling in cross winds. It would also take up a large amount of flat-deck space otherwise available for helicopter operations and aircraft parking.

However, it should be stated that it is not necessary for the ramp to be an exact tangent to the flight deck at the point of intersection. A discontinuity of less than 1 degree, or a slight step, may even be an advantage to excite the undercarriage and help it to 'unstick'. A possible solution, to at least some of these problems, would be the use of a lattice ski-ramp, perhaps similar to the three-rail ramp proposed by Fozard [1], but this would have its own disadvantages.

The profile of the ramp should be a smooth continuous curve without 'peaking' due to transverse welds and structure, which can set up vibration in the undercarriage. A let-down section, at 4 degrees below the final angle of the ramp, should be arranged to ease the compression of the undercarriage. After that, the end profile can be of any reasonable form, having in mind the airflow over the ramp, which should be as smooth as practical. Various forms have been used for this 'nose', but it should be remembered that, unlike conventional Aircraft Carriers, the ship need not necessarily be headed into the wind for take-off, and hence turbulence arises from both the end and the sides of the bow and ramp.

2.3 Effect of Head Seas on Aircraft STO Performance

The military worth of an aircraft carrier is largely dependant upon its ability to deploy its aircraft safely at any time, in sea states likely to occur in its intended operational area. One way of measuring this worth is by predicting the probability that the effective aircraft launch bow-down angle exceeds a pre-defined limiting value. In the case of V/STOL aircraft carriers, the prediction method should, ideally, take account of:

- aircraft take-off performance variation with all-up weight, runway length and wind over deck;

- the location and exit angle of the ski-ramp;
- the ship's motion characteristics at all headings and significant wave heights and ship's speed;
- the sea spectrum appropriate to the ship's operational area.

These factors have been incorporated into a computer program, which was developed by the author's Company, to evaluate aircraft launch effectiveness with varying ship and aircraft parameters.

A typical set of results from this program is presented in Figure 2, which shows the variation of significant values of ship motions at the forward end of the flight deck, with significant wave height, and Figure 3, showing the probabilities that the initial flight trajectory will be greater than, or equal to, 2 degrees down. From Figure 3, the improvement in flight safety obtained by changing the ski-ramp exit angle may clearly be seen.

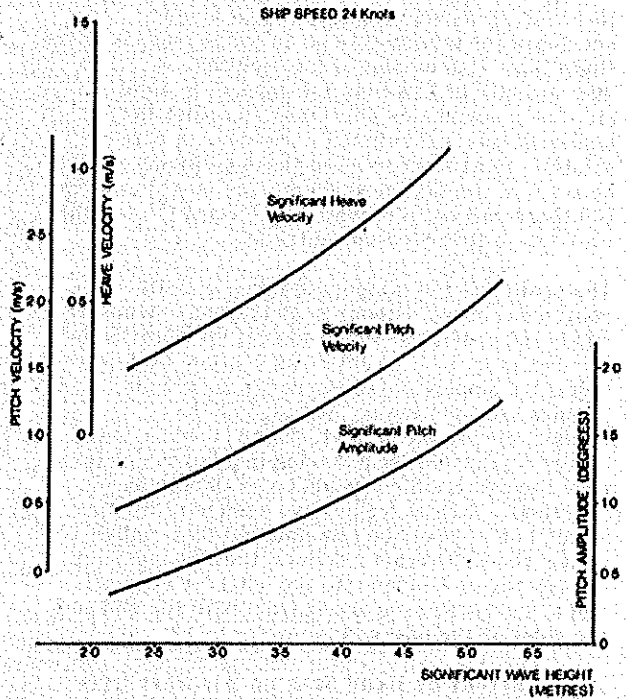

Figure 2 Ships Motions at Bow in Head Seas

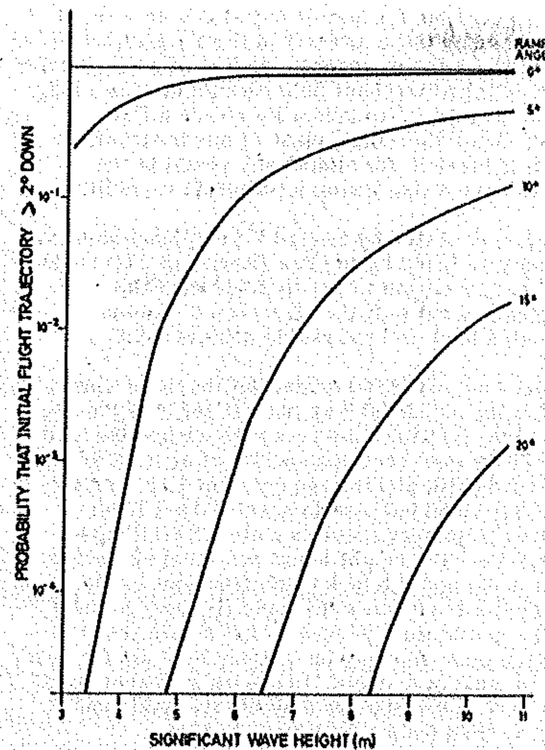

Figure 3 Effect of Ramp Angle and Wave Height on Initial Flight Trajectory in Head Seas

Using British Aerospace data on rates of change of Harrier Launch Speed with pitch angle, pitch velocity and heave velocity, the program may also be used to determine safe Harrier operating envelopes for a given ship.

3. REQUIREMENTS FOR V/STOL CARRIER

3.1 Flight Deck

From the above discussion it may be seen that to operate a Sea Harrier in the VTO/VL mode, requires, in theory, a flight deck of minimum 7 metre radius, but which gives the ability to deploy only half the aircraft's maximum disposable load, 2,200 kg.

In STO mode, aircraft payload may be increased by 9 kg/metre of deck run. A wind over deck (WOD) allows the deck run to be reduced by 3.3m/knot WOD, at a given payload.

A 15-degree ski-ramp allows aircraft launch speed to be reduced by up to 50 knots.[4]

Thus, a purpose-designed V/STOL Carrier must be able to accommodate a flight deck/ski-ramp arrangement of about 12m width and of sufficient length to allow aircraft to be launched with the required payload to carry out the perceived operational task. On its own, this requirement would suggest a rather small ship. However, if a high tempo of air operations is to be carried out, it is necessary to provide flight deck parking areas and run-up areas clear of the main STO runway. In addition, the whole concept and safety of air operations may be improved by siting aircraft lifts clear of the STO runway.

Despite the high temperature of aircraft exhaust gases directed at the deck during vertical take-off or landing, there is insufficient time for significant heat transfer to take place. However, when running up aircraft engines the high temperature and buffeting of the deck is likely to cause damage to equipment in the vicinity. Rein and Ryan [5] suggest the use of a water-cooled grid incorporating a hold-down device for deflecting exhaust gases overboard during engine run-up.

3.2 Effect of Self-defence Weapons on Flight Deck Arrangements

It would normally be considered essential for the Aircraft Carrier to have some kind of self-defence capability. The siting of a Close-in Weapons System (CIWS), with adequate arcs of fire, may affect the flight deck arrangement. The points to be considered are:

- to reduce danger to personnel and aircraft and the risk of ingestion of debris from sabots, etc, the CIWS must not fire across the flight deck;
- to minimise damage from aircraft exhausts, the CIWS should be well clear of the aircraft run-up areas.

These requirements tend to suggest fitting the CIWS on sponsons below flight deck level on each side of the ship, clear of the landing and take-off paths to avoid buffeting vibration and damage. For these reasons, coverage of the port side of the Carrier is difficult to achieve, as sponsons below flight deck level can be very close to the waterline. Coverage of the starboard side is easier, as mountings may be placed on, or forward of, the island structure with arcs of fire to starboard from ahead to astern. An alternative solution may be to fit a vertical launch point-defence missile system, taking up a minimum of valuable flight deck area.

3.3 Hangar

In addition to the flight deck arrangement, the maximum ship size may well be governed by the hangar arrangement. Clearly the hangar, plus flight deck parking areas, must be of sufficient capacity to accommodate the required Air Wing. Although the stowage of aircraft on the weather deck for prolonged periods of time might be acceptable in wartime, this practice, especially in small ships with higher probability of deck wetness, is not to be recommended. Also, to maintain sustained air operations, facilities must be provided for rapid refuelling, re-arming and maintenance of aircraft.

Although relatively small in size, the present generation of V/STOL Aircraft, the Harrier and Sea Harrier, and AV-8B, do not incorporate folding wings, and thus require a rather large hangar deck area and aircraft lifts, particularly as it is desired to move aircraft past each other in the hangar at sea. This necessitates a hangar width of at least 23m, to provide the necessary clearance for Sea Harriers. If aircraft cannot be handled in this way aircraft operations are restricted, particularly if only one lift is operating, as serviceable aircraft can be 'locked in' by unserviceable ones. Also, owing to the diverse operational requirements of this type of vessel, it would seem prudent to make the hangar and lift arrangement compatible with large helicopter operations, eg Sea King, EH101, or Chinook. Carriage of such helicopters may well govern the height of the hangar, as the V/STOL aircraft itself is relatively low.

A further consideration is the arrangement of the magazine spaces, so that the aircraft weapons may be brought to the hangar, or flight deck, and be loaded onto the aircraft with the minimum of delay.

3.4 Other Considerations

As has been shown, wind over deck - although of advantage - is not as vital in V/STOL operations as it is for conventional fixed-wing Aircraft Carriers. Thus, it is not normally necessary for the V/STOL Carrier to have the high top speed, 30+ knots, of a conventional Aircraft Carrier. This can represent a very significant saving in terms of weight, space and expense in the machinery arrangement. In fact, a V/STOL Carrier can launch aircraft in harbour, or even over the stern.

The seakeeping performance of the Carrier is also very important. Large ship motions and deck wetness, as well as limiting flying operations, can also lead to aircraft damage during handling, both on deck and in the hangar, and hamper aircraft maintenance. Comstock, Bales and Gentile [6] have shown that V/STOL air operations are severely limited by seakeeping performance, at displacement much less than 15,000 tonnes. Thus, seakeeping may be a significant factor in deciding the minimum size of Carrier.

Stabilisers can be very effective in reducing roll, but pitch remains a problem - 3 degrees of roll or pitch is about the limit that can be accepted for aircraft handling on deck or in the hangar.

4. INVINCIBLE

4.1 Evolution of Design

The evolution of the design of this vessel, the first of a new class of very significant warships for the Royal Navy, has been well documented [7].

The original Naval Staff requirement was for a ship capable of:

- command and control of a large ASW force, including ships, submarines and aircraft;
- providing a force of large ASW helicopters (Sea King or replacements);
- providing a contribution to area air defence.

Specifically, the design was to have a hangar capacity for nine Sea King helicopters, and three helicopter operating spots. Thus the design evolved as a 19,500-tonne vessel with through deck, island superstructure to starboard and a below-deck hangar. For reasons already given, the design had basic features necessary for the deployment of V/STOL aircraft, although this was not an original requirement of the design. For Area Air Defence the Sea Dart missile system was incorporated.

In 1975, by which time the ship design was well advanced and the order for the First-of-Class had been placed with Vickers Shipbuilding and Engineering Limited, the Sea Harrier was approved and formally incorporated into the Invincible design. Later, a ski-ramp was incorporated and this was constructed on the forward end of the flight deck after Invincible had been launched. The ramp exit angle was limited to 6 degrees, so as not to impair the arcs of fire of the Sea Dart Launcher. On the third of the Class, Ark Royal, the Sea Dart has been repositioned and the ramp exit angle increased to 12 degrees. She is the first RN Ship to have an integral ski-ramp.

As originally designed, the Invincible Class did not carry any form of close-in weapon system, relying on her aircraft, Sea Dart and escort vessels for defence. However, after the Falklands conflict, Phalanx CIWS have been added. Invincible and Illustrious have these mounted on their flight decks and forward but Ark Royal incorporates a purpose-designed sponson aft, and one additional mounting on the superstructure, firing to starboard.

4.2 Description of Invincible Design

The Invincible Class are handsome ships of a size comparable with Light Fleet Carriers of the World War II era (Figure 1). Their COGAG propulsion machinery has been described in detail by McKenna and Rogers [8].

4.3 Limitations of Invincible Class for Export Market

The Invincible Class have proved a resounding success for the Royal Navy. During the Falklands campaign Invincible broke all records for continuous Carrier operations - spending a total of 166 days continuously at sea, a great tribute to those who designed and built her.

However, these ships were designed to carry out specific operations in a NATO theatre of war and were not purpose-designed to carry V/STOL aircraft. In this context the hangar and lift arrangement is far from ideal for V/STOL operations. In particular, the high standards of construction and extensive C^3 equipments on the Invincible Class makes them relatively expensive, and probably beyond the reach of many potential export customers.

As a result of in-service experience, the Royal Navy have built many improvements into the Ark Royal, third ship of the Class, and it is understood that many of these will be retro-fitted into the earlier ships. These improvements include extra accommodation and rearranged workshops to suit a revised aircraft complement, using the empty spaces in the upper region of the hangar. Also, a closed-in Forecastle Head, as well as the CIWS improvements already mentioned, have been fitted.

5. AIRCRAFT CARRIER DESIGNS FOR EXPORT

During the build of the Invincible Class it was realised that a considerable export potential existed for the replacement of World War II vintage light fleet carriers, then in service with a number of overseas navies. To meet this need, the Authors' team embarked upon the development of aircraft carrier designs. These designs were directed towards a number of potential customers but Canada, Australia and Argentina have, for one reason or another, ceased to be interested. These designs will be described briefly below, though not necessarily in chronological order.

5.1 Invincible Variations

It was early realised that if V/STOL aircraft were to be operated from these ships, the restricted width of the hangar, which does not allow two Sea Harriers to pass each other, would be a distinct disadvantage (Figure 4).

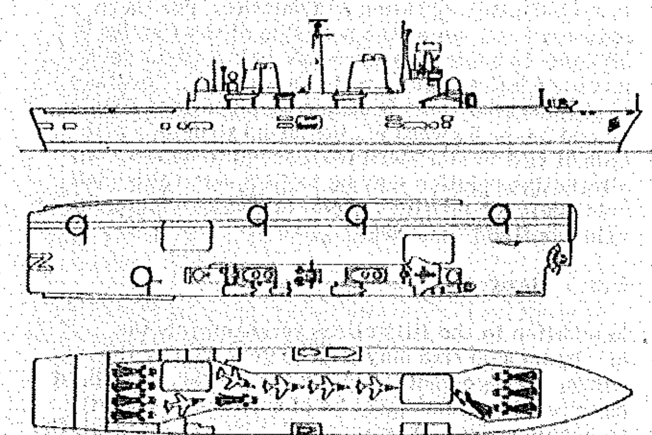

Figure 4 HMS Invincible

It was found that, by using the latest type of spray eliminators and turning the plenums of the air intakes for the gas turbines to give the greater dimensions fore and aft, and with a minor increase in extreme beam, it would be possible to straighten the hangar to allow two aircraft to pass (Figure 5). At the same time, investigations were made into alternative forms of propulsion machinery, including gas turbines and diesels.

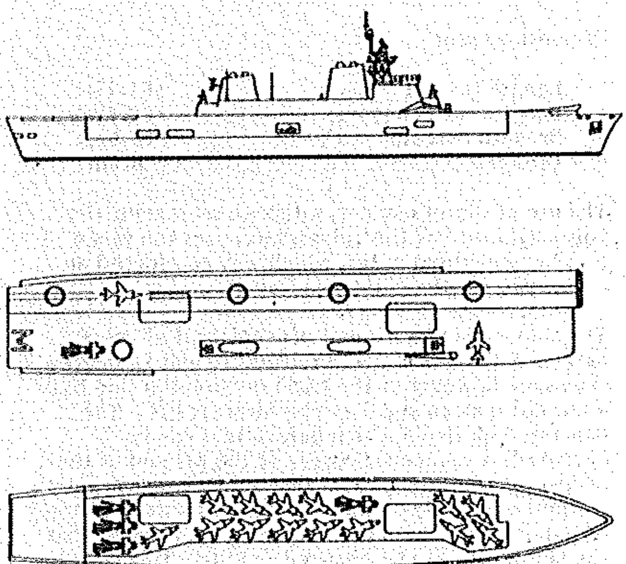

Figure 5 VSEL Modified Invincible

As the V/STOL aircraft would provide the primary defence of the ship against air attack, the Sea Dart missile system was eliminated, a CIWS system being fitted for defence against sea skimmers and anything else that penetrated the carrier's primary defence screen.

Further savings could be made in C^3 facilities if the vessel were to be operated as a private ship.

Investigations were also made into increasing the range for countries which have long coastlines and few bases.

5.2 Maritime Area Control Ship (MACSHIP) (Figure 6)

Design of this concept started in 1977 when it was realised that the V/STOL concept had a future in Maritime Warfare.

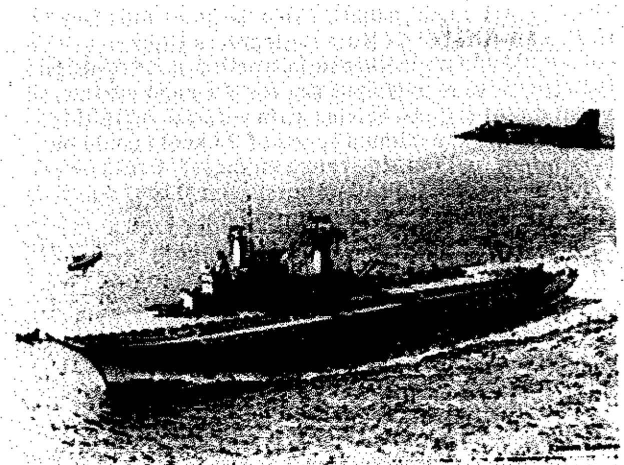

Figure 6 Artist's Impression of the Macship

Various concepts were examined, including one with a centre island and two runways, one on either side of the island (Figure 7), thus avoiding carrying the gas turbine uptakes and intakes across the ship, a configuration which uses valuable volume inside the ship. However, the concept finally decided on was a 13,000-tonne ship with a conventional side island and 10-degree ski-ramp, having dimensions:

- Length overall 181.0m
- Length, waterline 165.0m
- Breadth of Flight Deck 33.5m
- Breadth at Waterline 25.0m
- Depth to Flight Deck 18.95m
- Deep Draught (excluding Dome) 6.0m

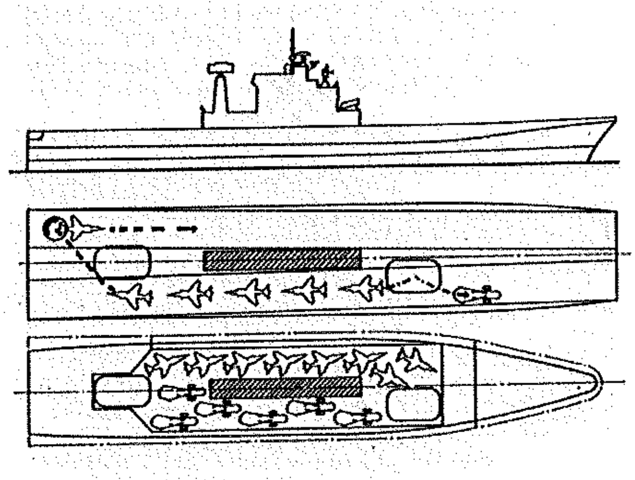

Figure 7 Macship Layout – Concept 1

The aircraft complement of this design is nine Sea Harriers with six Sea King Helicopters (these numbers could be increased in Wartime). Propulsion is CODOG, using Olympus gas turbines and medium-speed diesel engines driving twin screws. With this power plant, a maximum speed of 28 knots could be maintained and cruising range on diesels would be 7,000 nautical miles at 18 knots. The ship's complement would be 760.

The roles envisaged for this ship are:

- anti-submarine operations,
- area and point defence,
- engagement of hostile and shadowing aircraft,
- air strikes against land and sea targets,
- maritime reconnaissance and surveillance,
- landing and recovery of ground force units by boat and helicopter,
- tactical and logistic support to ground forces,
- command, control and co-ordination of sea, air and ground forces.

Even at a predicted cost of about 60% of that of the Invincible Class, it was realised that if the average customer were to be able to afford such a relatively expensive ship, there had to be considerable versatility - so that the ship could be used for such duties as aircraft ferrying, transport of heavy vehicles and peacetime disaster relief. Thus a customer navy could gain the support, rather than the opposition, of sister air and land forces.

5.3 The Vickers Versatile Aircraft Carrier (V/VAC) (Figure 8)

As a result of discussions it was realised that by a system of containerisation and add-on modules the initial cost of such a ship could be reduced - for instance, in the basic ship only one aircraft lift would be fitted. An aft end add-on module would then allow the ship to be built up gradually to a full capability - and incorporate additional or alternative roles.

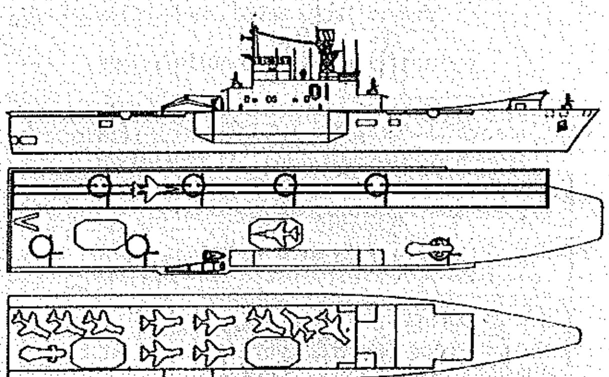

Figure 8 Vickers Versatile Aircraft Carrier

This philosophy led, in 1979, to the development of V/VAC (Vickers Versatile Aircraft Carrier), which was a vessel of 13,000 tonnes deep displacement, and propelled by medium-speed diesel engines, driving twin screws. (It should be noted that V/VAC was so named before the Versatile Corporation of Canada took over the old Vickers plant, and is not connected in any way with the 'Vickers Versatile' Corporation of Canada.) The ship would be designed to Merchant Ship Standards, except for essential naval features.

Dimensions are:

- Length overall 184.75m
- Length, waterline 173.75m
- Breadth overall 35.5m
- Draught 6.0m

The use of diesel engines, although increasing the noise signature of the vessel, increases the range to 10,000 nautical miles, which was considered an advantage for the duties envisaged.

The ship looks like a small conventional aircraft carrier with an island superstructure and 10-degree ski-ramp, however in the basic version the ship has a cut down stern and only one aircraft lift. The quarter deck (from which helicopters can be operated) is reached by doors at the aft end of the hangar. The most unusual feature is, however, a container hold for 32 ISO containers forward of the island, provided with the necessary services so that the ship's role can be changed readily. This would imply, of course, that the operator of the ship would have to stockpile containers outfitted for the various roles envisaged, and arrange to ship them in a container port, as the vessel would not have her own handling arrangements. These could be arranged, but to the detriment of some of her aircraft handling facilities.

The fully-developed version has a stern module fitted and a second lift. A stern or quarter ramp could also be fitted in the stern module, thus facilitating the embarkation of aircraft or military vehicles.

The design is flexible enough so that if the forward container hold is not required the hangar can be carried through, thus allowing for extra aircraft to be carried. The ship would then be configured as a conventional Aircraft Carrier, but diesel propelled.

The number of aircraft could be as high as 12 Sea Harriers and two Sea Kings, with a complement of 760 men in the fully-developed version.

As with the MACSHIP the ship's primary defence would be in her aircraft, but a CIWS system would be fitted.

5.4 Light Fleet Carrier (Figure 9)

In 1982, after the transfer of Invincible to Australia had been cancelled, the Royal Australian Navy decided that a new Carrier would be built to replace HMAS Melbourne, and a team was sent over to this country to collaborate on a Carrier design which would satisfy their requirements.

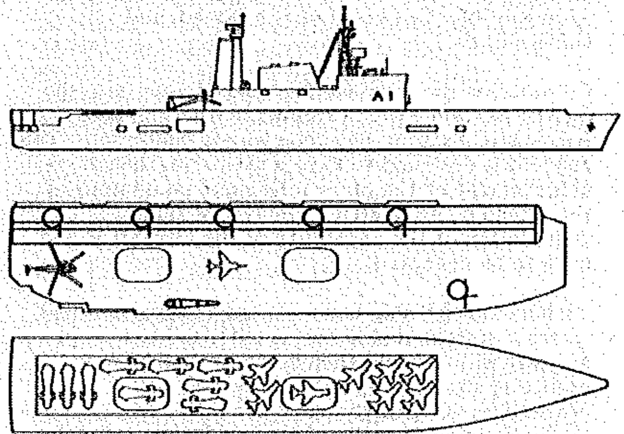

Figure 9 Light Fleet Carrier

This move by the Royal Australian Navy triggered off the development of the Vickers Light Fleet Carrier. Unlike the previous designs developed by the Company, the Light Fleet Carrier was developed under a unique working relationship whereby the full weight and experience of the Royal Australian Navy's Liaison Team was brought to bear. This team provided the vital ingredients of knowledgeable operational and technical expertise in a manner unique in a Shipbuilder-to-Navy relationship and which deserves to go on record as a significant achievement. Within the short space of some five months, working from the Royal Australian Navy's Statement of Requirements, and backed by the comprehensive knowledge of the two teams working together, a satisfactory cost-effective design was completed.

VSEL record their gratitude to the Liaison Team for their knowledgeable, enthusiastic and unselfish contributions, and thank the Royal Australian Navy for making that possible.

The Australian Navy's operational requirements were, from the standpoint of past Aircraft Carrier designs, unusual. Because of their long coastline and long-distance patrols in the Pacific and Southern Ocean, extremely long range was required, coupled with the ability to refuel and resupply escort ships.

At this time it was also realised that the amount of money available would be limited, so a dual approach was called for that would provide for the building of a basic ship with the in-built flexibility to add sophistication on later.

Various alternative designs were examined in order to reach the final compromise, which was a ship of 24,000 tonnes deep displacement, having dimensions of:

- Length overall	203.0m
- Length, waterline	190.0m
- Length of Flight Deck	184.0m
- Breadth at Waterline	27.4m
- Breadth of Flight Deck	36.4m
- Draught	7.7m

The functions of the ship were to be:

- Deployment of aircraft for anti-submarine operations - fighter protection with strike capability against land or sea targets - and reconnaissance.
- Provide bunkering capacity for associated Naval vessels.
- Maintain operational control and direction of aircraft.
- Act as Command Centre for a Task Force.

The basis for the hull form was the Liner Empress of Canada, with the power increased to give a service speed of 24 knots under tropical conditions. The propulsive power was provided by two controllable-pitch propellers driven by two LM2500-30 marine gas turbines (these being common with those fitted in other ships of the RAN). The range at 18 knots in tropical conditions would be 5,000 nautical miles, with a margin of fuel remaining.

The STO runway was arranged on the port side of the flight deck, terminating in a 12-degree ski-ramp to enhance V/STOL aircraft performance. A fuel replenishment rig was located outboard of the island, plus a fixed high point for reception of liquids. The aircraft crane provides a third replenishment high point, as is usual in Carriers. There would be a light jackstay in addition.

2,500 tons of fuel, plus appropriate quantities of aircraft fuel, fresh water and stores, were to be carried for escort replenishment.

The vessel was configured to carry a normal complement of eight V/STOL aircraft and nine helicopters. All of these aircraft could be stored in the hangar, there being room for four of these forward of the forward aircraft lift, for maintenance clear of aircraft operation. The aircraft lifts are of the conventional chain-operated type, using electric drive and are situated clear of the STO runway, so as not to inhibit flying operations in the event of any lift jamming.

For the carrier's own Point Defence, two CIWS mountings were provided for, one forward on a sponson below the ski-ramp and one aft on the starboard quarter, thus giving nearly all-round coverage with a minimum number of mountings.

The ship would be constructed to the requirement of Lloyds Register of Shipping, except for specific naval features. Accommodation was provided for a complement of 998 officers and men.

Unfortunately, despite the great hopes for and confidence in this design, as happens with many major projects, together with HMAS Melbourne and her Fleet Air Arm, it did not survive the reassessment of Australian Defence Policy.

6. FUTURE DEVELOPMENTS

6.1 Containerised Air Capable Ships

A number of concepts have been tried during and since the Falklands campaign, the most notable of which was to outfit merchant ships using containers and temporary flight decks. A limited success was achieved with the idea, but it has been found that the commercial container has many limitations when used in this way. In particular it was noted that individual containers leaked, securing arrangements were inadequate and stacks of them did not provide a watertight structure. In addition, the basic merchant ships chosen for this work are limited in the number of propellers (most are single screw), in speed and in their ability to withstand damage.

It was considered that a better course of action would be to provide purpose-built structures or containers and wherever possible, place them below deck.

Most conversions of this type have been as helicopter carriers, though of course if the limitations in performance associated with vertical take-off are accepted, V/STOL aircraft could also be operated from them. Notable among these is RFA Reliant, which is being used as a trials ship for the ARAPAHO System. ARAPAHO is a United States Navy idea and was conceived to provide short-term air capability, it was not intended that such ships would be effective in the longer term. Following the Falklands campaign, there was a need for a vessel in the South Atlantic to accommodate the Sea King helicopters of the Falklands Islands Garrison. It was decided that this would provide a suitable opportunity for a trial of the ARAPAHO System, with both the RN and USN having an interest in the outcome. RFA Reliant is a conversion of the 27,000 gross tonne single-screw container ship Astronomer and has a portable containerised flight deck, hangar with maintenance facilities, accommodation and storage spaces. In practice, it has been found necessary to substantially integrate ARAPAHO into the ship's systems, effectively removing its portability, and access into the ship's vertically subdivided hull has been hampered, denying the utilisation of an otherwise valuable bulk-carrying capability.

This ship has, however, provided many pointers for the future and it is understood that the new Atlantic Conveyor has built-in features to enable her to assume a similar role if necessary.

Another development along these lines is the Air Training Ship Contender Bezant - a twin-screw RO-RO Container Ship of 11,445 gross tonnes. Once more, her primary duties are to be as a Helicopter Training Ship, though the hangar is sized to accept Sea Harriers for limited airborne operations or for ferrying purposes. Conversion work is extensive, more so than Reliant, as the ship is to be permanently engaged in her new duties. Studies of merchant ships for this role revealed that very few were suitable, by reason of age, speed, and vulnerability.

Considering the schemes for V/STOL Carriers, the SCADS System - which follows closely the lead of the ARAPAHO System, has been widely publicised. This concept is designed to have a ski-ramp, though achievement of the close tolerances on contour of this would be difficult to achieve, or some degradation of the capability of the aircraft would have to be accepted.

Various 'garage' ship concepts have been examined, where a merchant ship hull is outfitted to accept aircraft which would then be controlled by naval escorting ships, in order to furnish convoy protection. One of the most promising of these was the conversion of a 100,000 tonne Tanker (of which, at the time, there were plenty on the world market) which of course, provides plenty of open deck space and close subdivision.

6.2 Skyhook

The concept of launching aircraft from cranes extended over the ship's side is not new. As early as 1914 the Russian Navy was proposing to launch seaplanes by hanging them from electromagnets on booms extending outboard, while the ship steamed at full speed into the wind [9]. The Skyhook concept provides for limited air-capability in small ships and, it is believed at the time of writing, will be the subject of a separate paper during this Symposium. It is not considered to be directly applicable to Aircraft Carrier design, although conceivably open deck area could be reduced by launching aircraft from ski-ramps or catapults and recovering them on Skyhooks, but bearing in mind the limitations on aircraft operations and handling due to ship motions in small ships.

6.3 Swath Ships

A breakthrough, with someone building such a ship for aircraft operations, cannot be too far distant. The ability of this type of ship to maintain speed with reduced ship motion in bad weather, and the flight deck area available in such ships, make it most attractive in the context of a convoy escort, or other aircraft operations.

The major disadvantage arising from the Swath concept are those of expense, damaged stability and draft. It is likely that such ships will be confined to open ocean duties for countries with deep water ports, unless some means of reducing draft for entering and leaving harbour can be employed. This could be achieved either by ballasting or by hydrodynamic depression, as in the Sea Sulky concept put forward some years ago. The former option increases damage control problems.

6.4 Supersonic V/STOL Aircraft

It is known that these are under development. Their use at sea will depend on the demand and the configuration. The existing 'broad wing' Harrier is as large as existing aircraft lifts will take, and even then the aircraft has to be carefully positioned diagonally on the lift. While the wing-span may not increase, such new aircraft are likely to be heavier and need yet longer runways than the present generation. This again will imply stronger flight decks and ski-ramps to obtain the best payload.

Altogether, the future is interesting.

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