150 YEARS OF SHIP DESIGN

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SUMMARY

As part of writing a short article entitled "Ship Design – From Art to Science?" [1] for the Institution's 150th anniversary celebratory volume [2], the author consulted the Institution's centenary book by K C Barnaby [3] to get a feel for the formative first hundred years of ship design recorded in the learned papers presented to the Institution. This consultation was motivated by consideration of the papers in the first volume of the Transactions of 1860, which, surprisingly, contained no papers directly on ship design, either on ship design in general or through describing the design intent behind a specific new ship. Rather, like the very first paper by Reverend J Woolley, the remaining 1860 papers concerned themselves with what could be called the application of science (and mathematics) to the practice of naval architecture as an engineering discipline. However this initial focus broadened out in subsequent volumes of the Transactions so that both technical descriptions of significant new ship designs and, more recently, papers on the general practice of ship design have also figured, alongside the presentation of progress in the science of naval architecture.

Given that the vast bulk of ships built over this period have been designed like most buildings to a set pattern, or as we naval architects would say based on a (previous) "type ship", those designs presented in the Institution's Transactions, and the few other collections of learned societies' papers, are largely on designs that have been seen to be of particular merit in their novelty and importance. Therefore this review looks at the developments in ship design by drawing on those articles in the Transactions that are design related. In doing so the papers have been conveniently broken down into the three, quite momentous, half centuries over which the Institution has existed. From this historical survey, it is then appropriate to consider how the practice of ship design may develop in the foreseeable future.

1. INTRODUCTION

To consider the development of ship design practice over the last 150 years through the papers read and discussed in the Institution's transactions, it is worth first summarising the particular nature of our form of engineering design. To do so one must start with the product being produced and, in this regard, ships are highly diverse. A useful division is to categorise ship types in terms of their design complexity and thus, in terms of the design issues, in regard to their usage. There are other ways of categorising ships, such as differing hull configurations (e.g. monohulls/multihulls, advanced/high speed hull forms, displacement/aero-lift/hydrodynamic lift/hybrid) or different propulsion types both of which, from a technical point of view, might seem more significant. However, the usage stance is considered to be more fundamental. Thus vessels, which are part of a wider transportation system, such as bulk carriers and container ships, are in this respect distinct from service vessels, be they offshore support ships, cruise ships or naval vessels, as the latter go to sea to do things, which are often unplanned and in response to unpredicted events. This can make the design process for these vessels more complex, at least in the initial design phase.

If the nature of ships is considered further, there are many issues which most complex (ocean going) vessels have to address. They have to operate in a demanding physical environment, which varies from extremes of cold and heat, as well as occasional violent and still unpredictable sea and wind states. Ships remain the largest manmade mobile environments. Most ship have very high endurance and even today, with reduced crews, are highly self sufficient; operating for, potentially, months away from land and support facilities. Ships are assembled using a large number of diverse technologies, from domestic systems of water, sewage and HVAC to, nowadays, the most advanced electronics. These subsystems all have to be designed into the whole system constituting the ship. Furthermore many of the subsystems are interdependent, so their efficient integration into a totality is a clear challenge. Most of this complexity applies to both categories of ship mentioned in the previous paragraph. Given the complexity of the end product that the designer sets out to achieve, it is worth emphasising that the design of a complex service vessel is also challenging because of the nature of the process of designing it. Firstly, most ships that have been designed have been so in response to a specific customer's need and thus are "bespoke", like a tailor-made suit rather than "off the peg", the latter approach being applicable to most other vehicles. In fact, from both a design view and considerations of manufacturing, a complex ship is more like a large civil engineering product, such as a bridge or modern art gallery, than being akin to smaller forms of vehicles, including the most sophisticated aircraft.

This neatly raises the next aspect in the nature of such ship design, that of the requirement the design is trying to meet. For a complex multirole vessel, intended to operate for many years and often in ways not initial perceived,

this identification of the requirement is thus not just the start point of the design process but also the most difficult part of that process. Given the consequences of getting this wrong, it is also that part of the process which has the greatest impact on the end product. This challenge to "work out what is really wanted" and what can be sensibly afforded, has been typified in the architectural and urban planning professions as the "wicked problem", i.e. working out the right requirement is more difficult than the subsequent part of the process of designing the product. It can also explain why the front end of the naval ship design process, in particular, is so often highly protracted – some of the argument for this can be seen from the debates recorded in the Institution's Transactions.

The next issue in this design process consideration is that the ship designer has many performance issues that need to be addressed. Clearly a lot of these will be associated with the perceived primary role of a given new vessel. However there remain general ship performance design issues, summarised by terms such as "S^5". Of these Speed (really Resistance and Propulsion issues), Stability, Strength and Seakeeping have been traditional disciplines for the naval architect (with a significant contribution, particularly regarding the propulsion aspects, from the marine engineer). The final "S^5" item, that of "Style", was coined to cover a wider range of stylistic issues, including margin policy, adaptability, survivability and a host of standards [4]. Some of these style issues have traditionally only been addressable some way into the design process, although increasingly the developments in computation and research are making these issues more amenable to consideration early in the design process. However, does require the environment in which the design is undertaken to be organised in a responsive manner able to provide the added investment in design effort that this entails.

It is axiomatic that naval architecture is ***the*** profession most directly concerned with the design of ships. As such naval architects may be considered to be the maritime equivalent of architects of the built environment, but there are significant differences from the design practice for that environment. This is due to naval architecture becoming one of the engineering professions, to which the early Transactions bear eloquent witness. Thus naval architects provide the equivalent of the built environment's civil/structural engineering capability, but remain the ship design equivalent to the architect, in providing the holistic design input. However, since the founding of the naval architectural profession in the ninetieth century, it has focused its education and research on the application of the disciplines of engineering science rather than the core skill of ship design, which was, traditionally, left to be "learnt on the job". Finally, this review may, for what has now become an international institution, seem a little UK centric but, of course, for the majority of the last 150 years Britain was internationally dominant, in both the naval and mercantile sectors.

2. SHIP DESIGN 1860 TO 1910

A perusal of K C Barnaby's Herculean survey of the first 100 years of the INA's existence as a learned society, for papers relevant to ship design, shows that the first half of that century was dominated by the setting up of the profession of naval architecture and coping with the incredible rate of the technical advances. The latter is exemplified by the difference between *HMS Warrior* (1860) and *HMS Neptune* (1910) or even the unique *Great Eastern* (1860) and *RMS Mauretania* (1908), all discussed in Transaction papers. The degree of innovation that occurred is indicated by Barnaby's summary titles for each decade: "Iron Ships, Turrets or Casements"; "Freeboard and Froude's Experiments"; "Steel"; Naval and Merchant Ship Developments"; "Boilers"; Triumph of Steam Turbines". The earliest papers on ship design *per se* were on naval ships and the arguments for armour and for twin screws. The 1873 discussion of the "extraordinary" *Devastation* were heated and characterised by the major involvement of very senior naval officers. This seemed to be the pattern with the Chief Constructor of the Navy (Director of Naval Construction (DNC) from 1875 to 1960) often having to defend new designs against both the profession and senior sailors. This open discussion of the latest designs, described by Sir Nathaniel Barnaby as "an annual pillory", reached a peak in Sir William White's 1889 defence of the *Royal Sovereign* design where the chairman Lord Hamilton, the First Lord of the Admiralty, said White "effectively flattened out Reed" (the previous DNC and still sniping from the wings).

While there were also papers on Russian, Italian and American naval ship designs, there was less discussion on the overall design of specific merchant ships, rather such papers focussed on specific technologies associated with steel, tonnage and marine engineering. Brunel's "Great Ship", the *Great Eastern*, was belatedly discussed in Elgar's 1893 paper comparing it with the "new Cunarders *Campania* and *Lucania*" and once again in 1907. There were papers on novel merchant ships, such as Scott Russell's of 1870 on Train Ferries, Reed's bizarre 1875 *Bessemer* with a "swinging saloon", Eldridge's 1891 paper on "Bulk Oil Tankers" and Smith's of 1905 on the Antarctic Ship *Discovery*. A near equivalent to the naval design "debates" would seem to be the various contributions by Martell of Lloyd's defending the Rules and bulkhead division standards, but there could not said to be papers on merchant ship design practice – perhaps the rate and diversity of development was too great to take such stock. Again, in the naval ship design discussions papers, in 1902 Laird Clowes' "Recent scientific developments and the future of naval warfare" and in 1903 "The effect of modern accessories on the size and cost of warships" by Whiting, show an intent to discuss sensitive design issues and engage the

naval operator which sadly rarely occurs today. Interestingly in the discussion on Whiting's paper Sir William White recognised "that gentlemen in possession of valuable (design) information…could (not) be expected to regard that information as other than a valuable asset.." and so the commercial pressures clearly prevented too much design detail being revealed, beyond "methods and policy of construction". So it is interesting to see that contributors, both in their papers and in discussion, to this day continue to provide as much design insight as possible to the wider profession through the Transaction papers.

3. SHIP DESIGN 1910 TO 1960

Barnaby's review in its second half is dominated by the two World Wars as his decades' titles reveal: "Test of War"; "Swords into Ploughshares"; "Shipbuilding's slow revival"; "War and Post-War Once Again"; and "Rapid Technical Advance". The second half century of the Institution commenced by looking back through reviews starting with the 1860 initiation of the Institution. Thus Dr Thearle of Lloyd's considered "Developments in Mercantile Ship Construction" focusing on the structural design implications in response to the massive growth in size of the average cargo ship, while Sir Philip Watts (the DNC) compared the British and French navies of 1860 and 1910 and highlighted in 1910 the greater concentration of Capital Ships in the Home Fleet (indicative of the growing German threat). Alongside discussing the new types of naval vessels in service by 1910 Watts compared the speed for a trans-Atlantic transit, which was typically four times that of fifty years before. By 1913 the open discussions on warship design were a thing of the past such that this had had a "frankness that was now taboo", thus discussion of Watts' paper on the fast battleships of the *Queen Elizabeth* Class was restricted to "a discussion of general principles".

The merchant ship community were less prolific than the naval community in design related papers over the first four decades in question, often papers were on novel ship types, including Sir E d'Eyncourt and H Narbeth's 1923 paper on a 600 ft passenger liner able to fly off aircraft – real Post-War "Ploughshare". More prosaic were L Peskett's 1914 "design of steam ships from the Owner's Point of View", S Carter's "Standard Cargo Ships", J Anderson's "New Merchant Ships" and M Denny's "Concrete Ships", all of 1918, with the latter a clear response to wartime material shortages. Wartime concerns were still present in 1920 with Prof Welch's "Merchant Ship Design in Light of War" and even in a paper by the Italian General De Vito in 1929 on "Atlantic Liners" looking at the design of the ex-German *Bremen*, acquired as war reparations. The 1924 papers by Prof Biles on "Ship design" (largely dealing with Resistance and Propulsion) and by J Anderson & Steele "Passenger ship design", showed a baseline design and the effects of payload and machinery changes. These were followed, in 1929, by A Wall & A Tabb's paper "Ship design and arrangements from the passenger's point of view" and signalled somewhat of a return to normality.

For the first two decades, of this period, naval ship design was dominated by the run up to and aftermath of the Great War. In 1911 Admiral Bacon's "Battleship of the Future" and Prof Welch's "Problem of Size in Battleships" were mainly about disposition of main armament rather than ship design directly. After the war there were numerous review papers, led by Watts' "Fleet of 1914", a comparison of the Royal Navy fleet with those of other major navies, and d'Eyncourt's "Naval Construction during the War" on the vast range of smaller vessels produced to win a global war at sea. Several papers in 1920 and 1921 looked at German designs: "German submarines" (Johns); German warship construction (d'Eyncourt); and *Baden* (Goodall), while Narbeth's 1922 paper "Three Steps.." considered the three battleship designs that led to the 1905 *Dreadnought*. Two major new designs were present by the current DNC: in 1920 "*Hood"* and 1929 "Battleships *Nelson* and *Rodney*", while examples of "unconventional vessels" were given in two airship papers, in 1919, C Campbell's "Airship Construction" and, in 1928, by the designer of the ill fated R101, V Richmond's "Rigid Airships".

Merchant ship design issues were more prevalent in the 1930s starting with Sir W Abell's "Safety at Sea" recording improved sub-division standards for passenger ships and a relaxation for mixed cargo ships and Sir J Biles' "Draught and dimensions of the most economical ship" showing reduced engine room costs and, daringly, suggesting future 60ft draught vessels. In the mid decade there were papers on fire-fighting arrangements, ventilation and welding, as well as Kent's paper on optimum lengths for pitch motion minimisation and maximum sea worthiness. Sir S Pigott's paper on the "Special Features of RMS *Queen Mary"* in 1937 described the great ship, which had been delayed by the Slump and Sir W Abell's "Channel Train Ferries", which was notable in 'fulfilling Scott Russell's dreams of the 1860s' to be contrasted by Admiral Thursfield's "Modern trends in warship design" pleading for 'smaller fighting ships despite the air threat' and Sir S Goodall's "*Ark Royal*" of 1939, a milestone design paper fulfilling the promise of Sir A Johns' 1934 paper "Aircraft Carriers", which had outlined the rapid evolution of this new type of Capital Ship.

The 1940s design papers are again dominated by war and its aftermath. The few merchant ship designs described are specialist: A Taylor's "Fishing Vessel design" (1943); E Stephens' "Thames Barges" and the need to replenish the fleet of 10,000 such craft in 1945; and finally Dr Corlett's "A light Alloy Cross Channel Ship design" in 1949 with a vision of a brighter aluminium future. There was also E Watts' "Crew accommodation in Tramp Ships" in 1945 reporting the change from 1914

fo'c'stle location to the slightly more kindly poop, with 2-3 berth cabins, and finally to amidships with "modern" galley arrangements. The naval design papers, largely in published in 1947, covered the full range of new vessels, from R Baker's astonishing variety in "Ships of the Invasion Fleet" and "Development of Landing Craft" through Watson's "Corvettes & Frigates", W Holt's "Coastal Force Design", H Skinner's "Depot & Repairships" and Dr Todd's "Experiments for the Mulberry Harbour" together with M Purvis' "Craft & Cable Ships for PLUTO" and C Merrington's "Ship repairing and Shipyard Problems in the Invasion of Europe". The latter papers demonstrated the immense technical efforts in the naval contribution to liberating Europe. There were also A Sims' 1945 "Habitability of ships under wartime conditions", which stressed the need to meet conditions from the Artic to the Tropics, N Holt & Clemitson's 1949 "Notes on the behaviour of HM Ships During the War", subsequently drawn on for the excellent seakeeping features of the post-war fleet, and J Daniel's "The Royal Navy and Nuclear Power", introducing another radically new propulsion technology. Submarines were covered by Sims in 1949 and A Starks on "German U-boat Design and Construction", while Dr Parkes, appropriately as a naval historian, drew down almost a century of battleships, in 1949, with "German and Japanese Battleships", but not without some criticisms of his observations from actual British battleship designers.

The ship design papers in the last decade of Barnaby's review are at last dominated by the non military with the only 'naval ship design' presented being Sir V Shepheard's 1954 "*HMY Britannia*", a comprehensive paper, actually drawn on nearly forty years later for the design studies of its not-to-be replacement. The other two naval papers were post war reviews: Captain James USN in 1951 on "US Fleet Maintenance & Battle Damage repairs in the Pacific " and in 1953 Admiral Fisher's "Fleet Train in the Pacific War", which further demonstrated the widening scope of naval ship design with the demise of "Big Gun Fleets". Cargo ship design figured significantly from 1952 with Sir E Ayre's "Merchant Ship Design", looking at future trends in speed, cargo handling and machinery types, and W Dickie's "High speed single screw cargo liners", describing eight new Blue Funnel ships, which were then compared by S Smith with P&O's "S" Class variants with, twin screw diesels versus single screw steam propulsion plant. In 1956 Dr Corlett discussed "On the Design of Economic Tramp Ships" to be followed two years later by Dr Gebbie on "Evolution of the cargo ship during the last 35 years - 'some thoughts on the future'". However, by 1959 the writing was on the wall as was clearly indicated by the American author D Argyriadis in "Cargo Container Ships", although that author foresaw infrastructure difficulties, which were to be met by container terminals on a scale inconceivable at the time. Other changes were indicated by two 1957 papers: the first on Iron Ore Carriers (J Lenaghan & R Atkinson) and the second paper which described such vessels "Built Abroad" – a less welcome vision of the rapidly declining future for British merchant shipbuilding. New types started in 1951 with a strange proposal by Professor Jaeger & Schokker, "A Proposed design for a combined research, training and cargo ship". More radical was Commander Du Cane's 1956 "Planing Performance, Pressures and Stresses in a High Speed Launch", welcomed in an area where most of the research had been extensively published in the USA, and also P Crewe's 1958 "The Hydrofoil Boat, Its History and Future Prospects". Finally, J Campbell's "Train & Car Ferries" reflected another future growth area in RO-RO vessels both for the Cross Channel trade and beyond, with Baltic and Canadian routes also being covered. The insights from outside the profession included the marine artist L Dunn's 1958 "Merchant Ship Design; Some Aesthetic Considerations", which still bears worth reading for the principles, even if fashion has moved on.

4. SHIP DESIGN 1960 TO 2010

Without the benefit of Barnaby, 'though with a subsequent check on the similarly sequentially organised two decade review by R N Newton [5], the current author has trawled the last 50 years of the Transactions to highlight the ship design papers. These have included a lot of specific designs (naval and merchant), as in the previous 100 years, but also, with the advent of electronic computers, papers on the ship design process, a topic not previously addressed directly. While the analytical power of computers has enabled naval architects to tackle, in a more scientific manner, what still remains challenging as an exceedingly complex set of physical phenomena that constitute the behaviour of a ship in a seaway, the use of the computer for designing new ships has changed that process out of all recognition.

The other thing that needs to be said in regard to the professional dissemination of ship design practice, in an increasingly international profession, is that the Transactions of the (now) Royal Institution (together with its American cousin's SNAME Transactions) no longer constitute the main sources of technical papers on the practice of ship design – or should it now be marine or maritime design? It would be invidious to try to mention all the major marine technology journals that now, to various degrees, publish technical papers on the nature and practice of ship design. In addition there are also both the standing international conferences, such as International Marine Design Conference (IMDC) and Practical Research And Design of Ships (PRADS) and the more specific International Conference on Computer Applications to Ships (ICCAS - very heavily CAD and CAM focused), and the many specific conference and symposia proceedings, particularly those published by the Institution, usually separately from the Transactions. The latter RINA conferences range from addressing one off issues, such as bulk carriers (1998) and new vessels (e.g. Trimarans (2000)), to frequent topics, such as

advanced high-speed forms, and annual conferences, such as the Warship conference run every June since 1984. There is, finally, the annual RINA presentation of "Significant Ships", which gives design details but without the very comprehensive and rounded background possible for those few designs presented in a full technical paper by members of the responsible design team. In addition in-depth descriptive, but less discursive, articles, usually on new merchant ships, also now tend to be frequently presented in the Institution's *Naval Architect* magazine.

In just looking at the more recent Transactions papers on ship design, published with their discussions and authors' reply, it would be possible to follow Barnaby's sequential approach for each of the last five decades. However it is considered that an overview is best done through considering the following themes: general design reviews; specific merchant ship designs; specific naval ship and submarine designs; novel ship and craft types; design issues, such as accommodation, or economic and environmental concerns and, finally, ship design methods and design practice. This way of looking back over the most recent half century has been chosen as it is felt to give a sense of how the view of ship design and ship design practice has greatly broadened, albeit from the specific perspective provided through the Transaction papers.

4.1. GENERAL DESIGN REVIEWS

This is a useful opening category of papers since it commenced in the 1960 Transactions with two large scale reviews of ship design (naval and merchant) in the proceeding century. Sir A Sims, as Director General Ships and Head of RCNC, presented a 60 page survey, without a discussion, of "Warships 1860-1960": their development (including comparison of the Royal Navy vessels with designs by the other major navies), development of a large number of new ship types and finally several selected technical developments. This major review coherently summarised a century of amazing change. J Murray of Lloyd's Register in 45 pages covered "Merchant Ships 1860-1960" showing the astonishing progress in ship size and speed. Sections were given on Ore Carriers, Oil Tankers, Cargo Liners and the naval architecture of Passenger Ships, with a second part on resistance and propulsion, strength and safety. This can now be seen to have occurred at the very start of a further major growth in ship size, particularly in VLCCs and Container shipping, both unpredicted at that point in time.

J Chapman's paper, also in 1960, on "the Development of the Aircraft Carrier" detailed the largely UK developments that were spectacularly adopted by the US Navy in its supercarriers. Sir A Sims' 1968 paper "Contribution of Warship Design to Industrial Technology" surveyed the developments in ship technology, including the naval contribution to merchant ship design. A significant review of "RN Post-war Frigate and Destroyer designs" in 1974 by K Purvis gave substantial details and summaries of Types 12, 14, 41, 42, 61, and County Classes. The same year S Palmer's paper "Impact of Gas Turbines on the Design of Major Warships" outlined the ship design implications of a major change in naval ship machinery, which at a stroke reduced complements substantially and reinforced the change that drove modern warships into being space, rather than weight, dominated. A similar review to that of Purvis was the Vosper Thornycroft "Family of Warships" presented by J Usher & A Dorey in 1982, on a series of successful designs, largely produced for smaller and, often, new navies. Its discussion alongside that on the Purvis paper provided considerable insight into the impact of modern technology on ship design. This was followed by A Dorey's 1990 "High Speed Small Craft", dealing with the lower end of this naval market, and by G Fuller's 1999 "Quest for the True Submarine", a review of another major UK post-War naval technological development. In the merchant ship world S Payne, as the Technical Director of Cunard and then Carnival, in his 1990 paper "Evolution of the Modern Cruise Ship" charted the return of the big passenger ship but now designed as the basis for a holiday itself, rather than being "the only way to travel", as had applied previously to the great Atlantic Liners before their demise due to the success of jet airliner. Payne updated this major expansion in fleets and ships' passenger capacity in his 1993 paper "From *Tropicale* to *Fantasy*: A Decade of Cruise Ship Development", a growth which shows little sign of slowing down in the 21st Century's first decade. A whole new type of vessels was surveyed by J MacGregor et al in 2008 in "A Family of Offshore Construction Vessels". At the other extreme, A Hunter in 1961 considered "Mainly on Small Ships and Fishing Vessels", S Macdonald et al in 1975 considered "RNLI Lifeboats in 1970s", A Rosyid & R Johnson, of ITS Surabaya, presented in 2005 "Developing Sustainable Fishing Vessels for a Developing Country", while I Parry in 2007 considered "A New Generation of Inland Waterway Maintenance Craft", all these papers showing, once again, the variety of ship designs the profession continues to address.

4.2. SPECIFIC MERCHANT SHIP DESIGNS

The most significant set of papers on specific ship designs have probably been those by M Meek, showing how the cargo ship changed from the 1964 "*Glenlyon Class* –Design and Operation of High Powered Cargo Liners" through the 'ultimate cargo liner design' the "*Priam Class* Cargo Liners – Design and Operation" (1969 with R Adams) into the modern container ships, whose development could be said to have been started by the very innovative *Encounter Bays* "First OCL Container Ships", presented in the year following the *Priam* paper and detailing the design impact of container handling and stowage. The series culminated in a mainly structural design paper on the large (274m), fast (26

knots) and fully developed Container ships of the *Liverpool Bay* Class (1972). A series of papers over the period have described specialist ships: A Webster's 1964 "Canadian Weathership"; B Baxter's 1973 "Hydrographic Survey or Research Ship"; D Dick & E Corlett's 1976 "Cable Repair Ship"; K Bengtsen & B Walker's 1980 "Modern Car Ferry Design & Development "; A Oliveira et al in 2006 "Modern Purse Seiner Fishing Vessels for the Portuguese Coastal Sea"; the same year P Truijens et al of Ghent University and LR Belgium "Design of Ships for Estuary Service" and R Cartwright et al in 2008 with "A low wash design of a River Patrol Craft with Unusual Environmental Impact". The latter could be said to highlight the main 21st Century concern, specifically reflected in an inshore ship design. A major specialist offshore ship like vessel, rather than the essential civil engineering based technology of the ubiquitous North Sea oil platforms of the 1970s to the 1990s, was presented in the Harland & Wolff 1999 paper by J MacGregor et al on "Design and Construction of the FPSO Vessel for Schiehallion Field". Finally going back to 1971 there was an update on one the 19th Century's hallmark ships; E Corlett's "Steam Ship '*Great Britain*'" not only presented Brunel's 1843 design but also the author's personal role in recovering for posterity and bring back home to Bristol this highly innovative vessel.

4.3. SPECIFIC NAVAL DESIGNS

At the small end of the naval scale in 1960 J Revans & A Gentry "The "Brave" Class Fast Patrol Boats" included a focus on the transom flat, which seems to reoccur regularly. Following on from Purvis' major review in 1974, the next generation of RN designs were presented as specific papers by leading members of the specific design teams in the UK Ministry of Defence (as the Admiralty has become), rather than the traditional DNC "authored" Spring Meeting paper. Thus A Harris in 1980 with the class of "HUNT Class MCM Vessels" applying the new Glass Reinforced Plastic (GRP) technology. The other end of the ship scale was A Honnor & D Andrews' 1982 paper "*HMS Invincible* – the first of a New Genus of Aircraft Carrying Ships", which produced an extensive discussion, including several senior naval contributors, welcoming back aircraft carriers to the RN after their demise over a decade before – something unforeseen in Chapman's 1960 paper. In the same year P Symons & J Sadden considered the novel "Seabed Operations Vessel", followed in 1999 by the first of two papers on the ultra quiet CODLAG powered Type 23 Class Frigate. This paper was read, in 1984, by Admiral L Bryson, the first (weapon) engineer Controller of the Navy, and was entitled "The Procurement of a Warship" but focused on the early stages of that Frigate design. It also had a rebuttal of the Thornycroft Giles 'short fat ship' proposal, which was never presented as a technical paper. Once the lead Type 23 was in service, a 1992 paper "Type 23 DUKE Class Frigate" was presented by T Thomas & M Easton (MoD Project Manager and Yarrow Shipbuilding director, respectively, indicating a move away from "in-house MoD design"). In between the papers on the Type 23 there was P Wrobel's 1984 "Design of the Type 2400 Patrol Class Submarine" on the last RN conventional submarine design, which was described in a level of detail unlikely to be provided on any design for the nuclear submarine fleet. YARD's design for the RFA "Logistics Support Ships" was presented in 1978 by B Baxter, followed by other YARD non-RN designs: M Rorly et al on the Danish "Corvette KV76" and, both in 1992, B Kay et al on "FRV *Corytes* Purpose Built Fisheries Protection Vessel" and D Watson & A Fritis "A New Danish Fishery Inspection Ship Type". In 1983 B Robson (the Royal Australian Navy's DNC) presented "Development of RAN GRP Minehunter Design". More recent designs, both for the RN and overseas navies, have been presented in, generally, a less formal manner in conference papers or, in the US Navy's case, in American journals. Papers on specific naval designs, like the merchant ship ones above, especially when accompanied by written discussion by the authors' peers and, less commonly than in the first 100 years, by naval officers, continue to provide invaluable insights into general and specifically naval ship design issues.

4.4. NOVEL SHIP TYPES

The Transactions continue to have designs for novel ship types presented, which can conveniently be split into conventional and "unconventional hull forms". The former start, somewhat 'unconventionally' with two submarine papers: E Wenk et al 1960 American paper on *Aluminaut* , "An Oceanographic Research Submarine of Aluminium of operations to 15,000 FT", followed by P Crewe & D Hardy's 1962 "Submarine Ore Carrier" proposal which was seen to require nuclear power, whereas E Corlett & G Snaith in 1964 "Some aspects of Icebreaker Design" and 1985 "Ice breaking Cargo Ships" by M Kanerva & B Lunnberg both seem worth revisiting today, with the opening of the Artic seaways. J Teasdale's 1967 "Modern Composite Ship – A Competitive Nuclear Powered Merchantman" was a 13,000 ton 21 knot Pusher and Cargo hulls combination proposal, with a novelty in keeping with some 19th Century concepts, while B Baxter's "Oceanographic Survey Ships" paper was presented the same year. In 2006 P MacGregor et al presented "Some Aspects in the Design of Compressed Natural Gas Ships" reflecting the insatiable need around the world for energy, which has led to novel bulk cargoes. In contrast two recent (2003) sailing ship designs were presented by S Wallis of Southampton Institute, "A Brigantine Rigged Sailing School Research Vessel (for the Woods Hole Institute in Massachusetts)", and by C Mudie on "Some parameters for the Design of 21st Century Sail Training Ships". Another contrast was provided by J Coates' paper on the "Naval Architecture of European Ored Ships" of 1994, which describes his recreation of the Greek Trireme design and its physical realisation for the Greek Navy.

Fast craft papers by A Bailey & N Warren of Fairy Brook Marine in 2003 on "Aircrew Training Vessels" and the proposal to rescue RO-Pax ferry personnel by "Fast Rescue Boats" by R Steen (2005) of Landsort in Sweden neatly lead on, in the next paragraph, to the many papers addressing unconventional high speed forms.

The first of the unconventional craft papers was P Crewe & W Eggington's 1960 "The Hovercraft – a New Concept in Maritime Transport", followed by A Bingham's "Hovercraft ferry" in 1964, and then in 1976 R Wheeler's "An Appraisal of Present & Future Large Commercial Hovercraft", which proved a false dawn due to the oil price rises. In 1965 R Lacey presented a "Progress report on Hydrofoil Ships" with J Inman & K Fisher's "Canadian Hydrofoil Programme" in 1966 and in 1971 "*Bras d'Or* – 200t Open Ocean Hydrofoil Ship" by M Eames & E Jones of DREA, also from Canada. Multihulls appear with H Parnham et al's paper in 1968 on "Class "C" Racing Catamarans", then E Corlett's 1969 "Twin Hull Ships", followed by in 1983 by G Smith of Glasgow University's "Design and Hydrodynamic performance of Small Semi Submersible SWATH Research Vessel", T Yoshida et al of Tokyo University in 2000 "the CS-Swath as a Trans Ocean High Speed Ship" and 2001 D Winters et al on "*Borgland Dolphin*- Creation of a Modern Semi Submersible Drilling Ship", showing extremes of possible usage of this seakeeping optimised multi-hull form. D R Pattison and J Zhang of University College London (UCL) in 1995 introduced the, then, new configuration of "Trimaran Ships". Earlier in 1984 D R Pattison had presented the "Design of a Sailing Hydrofoil –FORCE 8", while in the same year R Wheeler read the paper "Design development & trials of AP 188 Hovercraft" as a diesel powered response to rising fuel costs for high speed craft. The pleasure craft market was reflected in 2001 by J Guiton's "Seaworthy 'Planing' Cruiser/Racer" and high speed and unconventional reviews started with A Silverleaf & F Cook's 1970 presentation of, largely, hydrodynamic performance curves in "Comparison of Some Features of High Speed Marine Craft". This was followed by M Eames 1981 paper reporting on the NATO design studies of Advanced Naval Vessels entitled "Advances in Naval Architecture for Future Surface Warships" and a further Canadian paper in 1982, specifically on design methods applicable to SWATHs, by W Nethercote & R Schmitke "A Concept Exploration Model for Swath Ships".

4.6. SPECIFIC DESIGN ISSUES

This set of papers seems to have started, after World War II, with concerns over cargo handling and economics and has broadened considerably over the five decades. Sir S MacTier"s 1963 "Deep Sea Cargo Liner Design - A Commercial Reassessment" dealt with cargo handling, as did the following year's "Cargo Handling and its Effect on Dry Cargo Ship Design " by A Hopper et al as, indeed, did the 1972 paper by R Bennett "Recent developments in the Design and Operation of Fishing Vessels", since the latter was largely concerned with catch handling. "Economics Criteria for Optimal Ship Design" by R Goss in 1965 led to several related papers; by A Gilfillian in 1969 "Economic Design of Bulk Cargo Carriers" , then K Fisher in 1972 "Economic Optimisation Procedure in Preliminary Ship Design (Applied to Australian Ore Trade)" and 1974 "Relative Cost of Ship Design Parameters" and I Buxton's paper in 1972 on "Engineering Economics Applied to Ship Design", which was notable for introducing the Design Spiral, Discounted Cash Flow and optimal sizes for given speeds. J Carryette in 1978 with "Preliminary Ship Cost Estimation" provided valuable design data in a sensitive area and K Rawson's 1973 "Towards Economic Warship Acquisition & Ownership" presented a naval economic perspective. All of these economics focused papers, in part, reflected back to a day of papers read in 1965, and recorded in the Transactions as being on "Ship Maintenance & Associated Design Problems" which dealt separately with RN ships, passenger ships, cargo liners, cross channel vessels and oil tankers. A recent paper (2008) by M Bairman et al "Cost & Energy Assessment of a High Speed Ship" further extends economics to include current environmental concerns.

Accommodation has been a recurring theme: J Church in 1961 dealt rather specifically with "Crew Accommodation for Dry Cargo Vessels having Propelling Machinery Installed Aft", M Meek & N Ward (an architect) in 1973 on "Accommodation in Ships" put the case for a more thoughtful approach to 'internal architecture' of cabins and public spaces, J Cain & M Hatfield in 1979 in "New Concepts in design of Shipboard Accommodation & Working Spaces" reflected VLCCs & Containerships with high isolated deckhouses, while the same issues of improved living standards for seafarers was highlighted for the naval sector in 1988 by H Ware's "Habitability in Surface Warships" and a recent 2008 personnel movement simulation based vision was given by D Andrews et al of UCL and Greenwich University, entitled "Integrating Personnel Movement Simulation in Preliminary Ship Design". Electronics was specifically addressed in 1982 by P Gates & S Rusling's "Impact of Weapon Electronics on Surface Warship Design" and by E Harding et al, in "Micro Electronics in Operation Design and Construction of Merchant Ships" and again by Gates, in 1986, in a paper entitled "Cellularity: An Advanced Weapon Electrical Integration Technique". G Wilkinson in 1971 addressed "Wheelhouse and Bridge Design – A Shipbuilder's Appraisal" with a comprehensive exposition including a discussion from a joint reading with the Institute if Navigation, while a more specialist topic was H Tabb's 1975 "Escape from Submarines – A Short Historical Review of Policy and Equipment in the Royal Navy". Two recent papers address the application of new techniques to long standing issues impacting on ship design: in 2005 P Kulkarni et al of IIT New Delhi's

"Smoke Nuisance Problem on Ships - A Review " using Computational Fluid Dynamics (CFD) based computerised techniques and in 2006 D Andrews et al of UCL on "Design for Production Using the Design Building Block Approach", which used Computer Aided Ship Design (CASD) to improve Design for Production very early in both merchant and naval ship design. An earlier paper by R Turner et al of Vickers Barrow considered "Some Aspects of Passenger Liner Design" by comparing several alternative designs with regard to machinery choice and structural loading. More of a general review of naval ship design issues was given by D Brown & E Tupper in 1989 under "Naval Architecture of Surface Warships" and finally issues fundamental to the profession were presented in 1990 by K Rawson in "Ethics & Fashion in Design". Such reviews by (often) senior Ministry of Defence designers have enhanced knowledge on ship design through out the 150 years of the Transactions' publication.

4.7. DESIGN METHODS AND PRACTICE

This category seems to have grown immensely in the last forty years, largely due to the advent of the digital computer leading, particularly, to papers presented on ship design methods and approaches, reflecting also growth in design duration and effort applied, not least to meet demands for great safety assurance. However, this theme commenced with descriptions of computer aided ship design techniques and tools being addressed in the Transactions. A further related topic is that of the design environment, under which the wider managerial issues in ship design, particularly in the protracted and expensive field of naval ship acquisition, have been addressed in the last three decades, with some extensive written discussions, more typical of many lively discussions in the 19th Century, particularly in those days when major new ship designs were being presented.

The first of several CASD papers was one of two by I Yuille of the Admiralty Research Laboratory in 1970 "A System for the Online Computer Aided Design of Ships – A Prototype System & Future Possibilities": suitably forward looking, but now appearing very dated, in addressing Coons Patches and hull lines, yet already seeing the potential in terms of design efficiency and accuracy. Yuille's second paper in 1978 "Forward Design System for CASD using a Mini Computer" showed examples of actual ship compartments and major items of equipment being modelled, together with ship analysis by now being undertaken interactively. The same MoD system was addressed by the Ship Department's lead, S Holmes, two years later in "Application & Development of Computer Systems for Warship Design" with examples of initial structural design and considerations of through life computer design support. The then Brunel University team in 1989, J Keane et al, in "A Computer Based Method for Hull Concept Design" showed work for the UK MoD on a concept system distinct from the down stream main design tool development above. In the same year D Hally of the Canadian DREA in "On the Systematic variation of Hull Representation for Computers" showed the drive to tackle the ship designer's perennial issue of adequately capturing hull form definition.

The large number of papers on ship design methods and design approaches started in 1977 with the computer based "Concept Exploration – An Approach to Small Warship Design" by C Eames & T Drummond, also of DREA Canada, and can be seen alongside D Watson & A Gilfallin of YARD's paper "Some Ship Design Methods", a seminal presentation of merchant ship initial sizing, which, despite the subsequent era of rapid growth in ship size and types remains an excellent guide. D Andrews of UCL and MoD presented a series of papers on an architecturally driven approach increasingly justified by advances in computer utility: in 1981 "Creative Ship Design"; in 1986 "An Integrated Approach to Ship Synthesis" and in 2004 "Creative Approach to Ship Architecture" – all provoking extensive discussion on the nature of naval ship design, in particular. The Newcastle University team of W Hills et al in the 1989 paper "Integrating Ship Design & Production Considerations in the Pre-Contract Phase" looked at the merchant and offshore 'Made-to-Order' process.

A series of papers have considered the scope that numerical optimisation techniques might provide to improve ship design, started in 1991 with M Welsh et al "Application of An Expert Systems to Ship Concept Design Investigations" and A Keane et al, now at Southampton University, "Optimisation Techniques in Ship Concept Design" followed the next year by P Sen of Newcastle University with "Marine Design : The Multi Criteria Approach" and in 2007 by G Ernst et al "Application of Artifical Numerical Methods in Preliminary Sailing Yacht Design" which showed how a tradition design "art" was now part of the general CAD environment . Two UCL papers by W van Griethuysen in 1992 "On the Variety of Monohull Warship Geometry" and in 1994 "On the Choice of Monohull Warship Geometry" gave similar guidance for naval combatants to that by Watson and Gilfallin for merchant ship sizing and form selection. A series of more thematic design papers commenced with D Brown's 1993 "History as a Design Tool", followed by D Andrews of UCL's 2007 paper "Art & Science of Ship Design" and B Woods of Massey University 2008 paper on the "Role of Ambiguity in the Art & Science of Yacht Design". These were followed by two further papers by Andrews in 2004 on "Architectural Considerations in Carrier Design" and, with R Pawling, also of UCL, in 2008 on "A Case Study in Preliminary Ship Design", the latter included a review of preliminary ship design methods alongside a specific detailed design study's evolution, something not presented in any earlier paper.

The final group of papers on the practice of ship design started with D Andrews' two UK MoD papers on the "Management of Warship Design – the MoD Warship Project Manager's Perspective" in 1993 and "Preliminary Warship Design" in 1994 describing the process for a major concept design investigation. Again extensive discussions on both papers provide insights into practice in a time of rapid process change, while L Ferreiro & M Stonehouse of US Navy and UK MoD respectively, also in 1994, in "A Comparative Study of US & UK Frigate Design", separately presented to RINA and SNAME, led to both discussions being published in each Transactions, thus giving a wealth of insight into comparative design practice. D Brown bowed out in 1995 with "Advanced Warship Design, Limited Resources – A Personal Perspective" on naval ship design, while R Cripps et al of the Royal National Lifeboat Institution (RNLI) in 2005 in "Development of Integrated Design Procedures for Lifeboats" showed procedural matters are not restricted to the naval design sector. The following year P Gates, then with BAE Systems Marine, presented "Design Authority of the *Daring Class* Destroyers" showing how the traditional UK MoD design responsibility had been passed to industry, not without some quizzical views being expressed in the discussion. Finally in 2009 P Gauleni of Genoa University and N Dazzi of OSN Italy in "Naval Architecture & Systems Engineering : A Deal for Naval Ship Design Evolution" posed a history based analysis to suggest a systems based approach to D Brown's 1995 resources dilemma, leaving ship design still searching for coherence in an increasingly uncertain future.

5. THE FUTURE OF SHIP DESIGN

From the above survey of the ship design related papers captured in the 150 years of the Institution's Transactions, it is clear that papers on ship design constitute an important record of the naval architect's primary function, that of producing ships to meet the needs of our various customers, users and wider society. The Transactions continue to record discussions by other ship designers, specialists (including increasingly academic researchers) and operators on the designs presented, which are often prestige and novel vessels, and, increasingly, also on the new design tools and methods being developed. All this adds greatly to the body of knowledge that is openly available to the profession in regard to ship design.

The overall impression gathered from surveying 150 years of ship design is of the rapid rate of change in ships recorded; substantial improvements in predicting and achieving enhanced performance; the large number of novel designs, issues and technologies presented; and the extent of the written record of the discussion on the nature of ship designs and the practice of ship designing. This has been an important part of the learned society role of the Institution for its first 150 years and it is important that this continues as the profession goes forward. Clearly in the future both ships and the practice of ship design will continue to change and to do so in ways, in which we can only partially predict. Thus there will be unforeseen issues, just as, for example, in two specific instances, that of the global extent of container shipping and of the all pervasiveness of digital computation. Yet both were un-predictable 150 or, even, 50 years ago.

The author feels, as is addressed in Reference 1, that the practice of ship design, at least in the artisan or craft sense, still does have "art" present in the nature of design practice, through the many large and small decisions the engineering designer makes, despite increasing pressure to automate much of ship design. However, the essential bespoke nature of ship design still means it is possible to use the ever growing power of the digital computer to allow the designer to have more freedom to explore design options and provide better solutions for an ever more demanding maritime environment. Furthermore, the vital creative element required of ship designers can now be emphasised as part of initial ship synthesis design through the exploitation of advances in computer graphics, so science and art can, and should, remain integrated together in preliminary ship design.

With the intent to foster creativity in the design synthesis of future ships, already there are developments underway, such as those to incorporate ever more sophisticated simulation tools into graphically driven preliminary ship design. Such developments can mean that ship design can become more creative and exploratory, through a comprehensive marriage of art and science. However in the future, this will require naval architects to acquire both a more creative and a broader knowledge base of skills, in addition to the traditional engineering disciplines that have been relied upon to date. So we can be sure that the future practice of ship design will continue to be as demanding and exciting in its unpredictability, as it clearly has been in the last momentous 150 years.

6. REFERENCES

The very many papers highlighted in this historical survey are all published in the RINA Transactions, so they are not detailed below. Those highlighted from the first 100 years are surveyed in more detail in Reference 3, as are many for 1960 to 1980 in Reference 5.

1. Andrews, D J: "Ship Design – From Art to Science", Article in Reference 2.
2. Blakeley, T (Editor): "150th Anniversary of the Royal Institution of Naval Architects", RINA London, 2010.
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4. Brown, D K and Andrews, D J: - "The Design of Cheap Warships", Proc. of International Naval Technology Expo 80, Rotterdam, June 1980. (Reprinted in Journal of Naval Science April 1981)
5. Newton, R N: “The Royal Institution of Naval Architects 1960 -1980”, RINA London, 1981.

