DISCUSSION

ENABLING TECHNOLOGY AND THE NAVAL ARCHITECT 1860-2010

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This Discussion was overlooked at the time of publishing the following issue. We apologise for the delay.

COMMENT

Professor P G Wrobel, University College London, UK

I have a brief comment to contribute: "This is a thorough review of the technical changes over the last 150 years in the Marine Sector. Even more interesting the author has linked these with the changing market and business drivers over that period. It also illustrates how the aggregation of all the individual changes represent several revolutions in the sector. Can I ask the author to now wind the story forwards and give his view of the future and what the marriage of "Technology Push" and "Market Pull" is likely to hold in store for the next 150 years. However disconcerting it might seem - the rate of change will not stop – the opportunities are legion".

Mr T McDonald, Atkins Global, UK

I would like to thank Dr Buxton for providing such an informative paper that clearly illustrates the impact of enabling technology on the variety and performance of both maritime vessels and their constitute systems.

While conducting your extensive review of these differing technologies did you note any common trends linking the technologies that have succeeded within the maritime field over the last 150 years? Were the successful technologies driven by strong individuals, did they possess considerable operational advantages, did external changes drive there adoption, or were other factors important?

Additionally, I am interested in your perspective and opinions of the emerging enabling technologies that may be suitable for tackling current significant challenges in Naval Architecture, including: reduction of carbon emissions (and other environmental issues); and growing complexity within marine vessels.

While the future is always difficult to predict, has performing your historical review of enabling technologies provided you with any insights into current developments that you feel are well placed to help tackle these issues?

Professor D Andrews, FREng FRINA, University College London, UK

The author is to be congratulated on his paper showing a highly professional mix of technical and historical survey of 150 years of maritime engineering development. This continues to flourish sustaining the global market, which remains largely dependent on the maritime sector despite the wider public perception, due to the major world movement of people being by air transportation. The strong message from the survey is how closely the naval architect and the marine engineer have worked together in making the highly impressive advances in ocean transportation over the last 150 years.

From a warship designer's perspective a greater post war change than adoption of gas turbine prime movers, highly significant though that has been – not least in the substantial reduction in engineering staff onboard [19], has been the move away from guns to missiles and, even more, the developments in radar, communications and now C4I (Command, Control, Communications and Computers plus Intelligence) all of vastly increased information levels due to the astonishing and still increasing information capacity provided by the electronics age. Thus in the naval ship design world we have a third major discipline in ship design – that of the combat system engineer. This was recognised by the Institution's first conference on Systems Engineering in Ship & Offshore Design in this anniversary year [20].

Noting that one effect of the electronics age which has already impacted on merchant ship design is the adoption of unmanned machinery spaces and use of autopilots for bridge control, the author is asked to comment as to whether we are close to the final step of wholly automated ships, or whether, like passenger carrying aircraft, there will always be a need for a human presence onboard major ocean going vessels. It could be argued that this may become no more than a psychological demand, if only to be seen to be providing an ability to intervene in the congested inshore waters, where there may well be small autonomous surface and underwater vehicles drawing on the technology beginning to be seen exploited for military air reconnaissance and even strike.

Mr C V Betts, CB, FREng, RCNC,m UK

This paper is a wonderful tour de force which covers virtually all the major developments in enabling technology since the Institution was founded. The rate of development is fascinating and impressive, told by the author in a way that is highly readable and includes many evocative pictures from past and present.

In a subject of such historic scope, it would be surprising if readers could not think of additional developments of significance from their own perspective. In my own case, some are covered by Professor David Andrews in his paper "150 years of Ship Design" and others might be covered by other review papers that I have not yet seen. Among the significant enabling technologies that I would add are the many developments leading to the modern aircraft carrier and also to the modern submarine powered, like the largest aircraft carriers, by nuclear reactors (ironically, most with virtually the last marine use of steam machinery) or by other means of extending underwater endurance such as the use of Stirling engines or, increasingly, fuel cells. The attempted use of nuclear power in merchant ships has also been of note, albeit not successful (so far) except perhaps in the case of Russian ice breakers.

One could add as a very significant development the huge space-and-power-demanding increase in the many forms of electronics, particularly but not only in warships. Regarding high speed and leisure craft, the author rightly mentions the far-reaching introduction of fibre reinforced plastics but the last of my additions would be the other technological leaps in materials and design methods used in the development of small service and leisure craft, particularly high speed monohull and multihull sailing vessels that are nowadays capable of circling the globe non-stop, and often single-handed, at average speeds in excess of 15 knots.

The author concentrates almost completely, and entirely reasonably, on the developments that have brought real improvements. It occurs to me that it would be potentially useful to the profession to commission a complementary paper on the significant mistakes made and the lessons learned from them over the years, particularly those that could well arise again if history is ignored.

Examples of the sort of issues that come to mind include the Royal Navy's disastrous attempt to increase the submerged endurance of manned submarines by the use of exotic fuels such as High-Test Peroxide (HTP) in the 1950's; the too-rapid increase in supertanker sizes in the 1970's which led to some major structural failures (compounded by poor understanding of the early finite element methods of structural design); the problems introduced by adding aluminium superstructures to steel hulls, leading to extensive cracking in passenger ships and increased vulnerability to fire in warships; the poor design and operating features which led to the unacceptable rate of loss, often with all hands, of large bulk carriers in the 1980's; and the recent and shameful series of major disasters with Ro-Ro ferries whose design for damaged stability continued for far too long to place economic 'efficiency' ahead of safety requirements and ignore the original and safer design features used in the precursor World War II landing craft. There are numerous other examples of mistakes and lessons learned that one could quote. To publish a paper on all these might seem to some to involve an unnecessary wallowing in our past sins and errors; however, we should not actually be too embarrassed to highlight our failures, as all forms of engineering have advanced through making and then learning from mistakes.

Mr N Pattison, BAE Systems Surface Ships, UK

The author is to be applauded for an interesting and highly informative paper which describes, in a very accessible way, the introduction and development of the various enabling technologies which have been the primary influences on ship design and construction over the last 150 years. The transition from sail to steam, the adoption of iron and then steel as the structural materials of choice and the early development of the science of Naval Architecture dominate the early years, while steam turbines, diesel engines and the introduction of welding are key technologies in the first half of the 20th century.

The influences of ever expanding international trade and economic shocks such as the sharp rise in oil prices are clearly described as well as the resulting trends for larger and larger ships and more specialised ships. Does the author expect that these trends are likely to continue and if so what sectors might be ripe for increases in vessel sizes and specialisation respectively?

The development of containerisation is outlined and its very substantial benefits in terms of flexibility and reduced handling times and labour costs described. The trend of increasing vessel size is evident in this sector but does the author anticipate other developments in this area over the next few decades?

Cdr C Dicks BEng PhD CEng MIMechE MRINA RCNC,Fleet Constructor, Navy Command HQ, Portsmouth, UK.

I should like to thank both Professor Buxton for his excellent summary of many lifetimes of achievement. It is quite humbling to realise the elements of one's profession that one is simply not aware of, or takes for granted! It is also important that such achievements are documented.

My comments are aimed in three directions: Where is the role of the naval architect heading? Are the students of today sufficiently aware of the achievements of their predecessors to learn from them? Is it appropriate that the public at large takes the capability of modern shipping for granted, if not how do we educate?

With regard to the first point I find myself torn, I can argue the current direction of travel is no longer "simply" towards using new technologies and knowledge to allow a new capability to be introduced, but one in which maintenance of today's level of performance with economy of effort, increasing levels of safety and reduced environmental impact are key. These challenges may lead to a different kind of Naval Architect or Marine Engineer to those pioneers detailed in the papers, a team member focused on technical risk, instead of individuals each pioneering ultimate levels of performance. Alternatively future resource and conservation challenges, Panama canal construction or deep water exploration, increasing demands from cruise passengers and high technology naval capability requirements will all demand that the technological edge is pursued and maintained, whether for profit, project viability or for military superiority. Will the author comment on whether the role of the naval architect will change in the foreseeable future and whether we are preparing our successors correctly for that future? Is our priority on teaching complex analysis methods the right one? Should we focus more on design, both theory and practice than at present? Is there a greater need for technology development skills?

I find myself reading the paper and wondering why, with the availability of M.Eng. degrees with a little more breathing space for subjects beyond the core disciplines, it is not generally a requirement for all undergraduates to study, the history of ship design, technology development or analysis. I would suggest that an understanding the development of solutions to problems past would be an invaluable tool to shape problem solving capability. Using previous technological advances as a way of introducing classical analysis approaches, would enliven heavily maths based courses. Possibly most importantly, such a course might provide an additional opportunity to increase the ability of the student to write a persuasive argument in a technical subject. Would the author consider this course a useful addition to the core curriculum?

By the appearance of this paper, and the one by Professor Andrews, in the Trans. RINA, the authors have succeeded in enthusing further an already enthusiastic audience. However, many consider the UK public to be “Sea Blind” to both Naval and Merchant shipping. While Formula 1, Discovery Channel and other popular media regularly take the public into areas of technological complexity without them switching off, our most prominent media appearances are safety or environmental disasters and project management mistakes. How do we enthuse the public into understanding how complex our endeavours are, how interesting they are and how they could be involved? My own start point is to propose that the next available Royal Institution Christmas Lecture series focuses on the different technologies involved in the concept design of a Submarine.

AUTHOR’S RESPONSE

I very much appreciate the thoughtful contributions from well respected discussers. There is no doubt that by taking a long period to review developments (as I did in Ref 3) it focuses on those developments which created long term trends, rather than simply being short term divergences from the main stream. As several themes recurred from discussers, I thought a general review would be helpful before addressing specific points.

For transport vessels (by far the biggest sector of the world fleet by tonnage), the three key advances have been related to size (much larger, enabled by better materials and structural design methods), speed (more modest increase, enabled by more powerful and efficient prime movers) and payload handling efficiency (liquid in bulk not barrels, mechanical handling of dry cargoes, unitisation). Each of those had remained almost unchanged for centuries until iron and steam triggered a steeply rising curve of any relevant performance measure from the mid 19th century. But more recently, some of those curves have levelled off appreciably, suggesting less dramatic changes in future. That future of course will continue to require large numbers of ships to transport raw materials, energy products, semi-processed materials and manufactured goods across a world 71% covered by sea and where locations of supply and demand rarely match.

On prime movers depending on combustion of a (fossil) fuel, we have gone from 5% to over 50% thermal efficiency. Given the physics of heat engine processes, there appears to be not much further to go even with very complex cycles. But a breakthrough would become possible if we could store electricity cheaply in large quantity at a good power density (unlike batteries). We would immediately change the ship energy source-to-propulsor efficiency from around 50% to over 90%. In principle, future electricity should be generated on land at lower real cost than from increasingly scarce fossil fuels of increasing cost (particularly oil), e.g. by advanced reactor technology or more efficient development of renewables. So cheap and easy storage of such electricity or perhaps that other high calorific value fuel hydrogen (probably stored in a different form from gas) would re-galvanise propulsion. LNG as a fuel has useful properties but is not fundamentally different from other fossil fuels. In some cases small scale novel reactors or practical high power fuel cells could have a similar effect. There seem few limits on propulsion power levels available, with 100s of MW possible, with multiple power sources and electric motors to multiple propulsors. But the latter too must be approaching limits of possible efficiency, thrust/torque.

So for ever bigger ships, propulsion power is not a technical barrier. It is more a question of economics and having to drive a hull through a viscous medium and possible new regulations. Perhaps some form of boundary layer control may enable a breakaway from turbulent flow levels of resistance, but already ships have lift/drag ratios approaching 1000 instead of the 10 of dynamic lift vehicles. Air cushions can help under favourable circumstances. Low value (bulk) commodities will never be able to afford to travel fast in terms of an acceptable ratio of transport cost to cargo value, so speeds in the 10-20 knot range seem unlikely to change, or even drop if increasing energy costs and/or environmental regulation demand. For higher value (manufactured) goods 20-30 knot speed seems to be another plateau for displacement hulls. The small volume of ultra high value cargo can always afford to travel by air. Is there a niche market for other premium cargo travelling at 40-60 knots in a high speed craft? The technology and the economics of such freight-only craft have yet to be demonstrated for long distance transoceanic voyages. Both lift must be increased and drag reduced before they become viable, so keep fuel load and costs to acceptable levels. For passengers, ships now only mean short sea transportation (ferries) or leisure (cruise ships). There is never likely to be a future transportation market for long distance passengers by sea. The long transit time means that much more elaborate accommodation features are needed than a single seat in an aircraft, which can be endured for the 24 hours or so which can get you to many places on the planet at an affordable cost.

While there are no fundamental limits on vessel size – Archimedes provides free lift – we have probably had most of the growth in ship size in many ship types. It is operational aspects rather than technology that provide the limits. Draft is a cheaper dimension to increase ship size than length or breadth. Deeper ports have been developed by dredging or re-siting closer to deep water. But we are approaching natural limits in many busy water routes, e.g. Dover Straits or Malacca Straits or the Baltic, so draft cannot increase much more for worldwide traders. A few industries can accept large cargo parcel sizes with their associated storage facilities, but such require faster cargo handling rates. With most ships now only in port for a day or two (compared with a week or two a century ago) there cannot be much more to go for in increasing cargo handling rates to reduce port time. Some ships are already spending 300 days at sea a year. The standard container revolutionised transport of manufactured goods as Nick Pattison notes. Given the huge existing investment in equipment and facilities and the limits imposed by road and rail transport, it seems unlikely that the ubiquitous 20 and 40 ft and related containers will be displaced by mega units for manufactured goods moving in relatively small parcels (one 40ft container full of tennis balls is probably enough). A possible exception is for semi-processed cargoes moving in large quantities like steel or forest products, but more likely in specialised ships rather than ‘container’ ships.

Transport ships have improved in the ratio of payload (deadweight excluding fuel) to all up weight (displacement) from around 50% to 86%, which is well above any other type of vehicle, so there too the curve must have nearly levelled off, however much exotic structural materials might be used.

The majority of discussers come from a warship background, so I am conscious that I should have devoted more time to the effect of technologies on such ships. Certainly for much of the period, military demands (and budgets) drove some naval architectural developments. Steam turbines and higher tensile steel drove design in naval vessels like destroyers a century ago. Nuclear power provided almost unlimited (air independent) propulsion, changing the submarine into a really effective deterrent, whether strategically (ballistic missiles) or tactically (Falklands). For military vessels payload (weapon and combat systems) drive the demand (reaction to threat) and thus associated design requirements. Classically the torpedo drove the demand for ever faster ships (destroyers), or more stealthy delivery vessels (submarines). Aircraft drove the design of a new type of ship, the aircraft carrier, the largest warship type ever. However warship size has not grown significantly in recent decades, unlike merchant ships, with container ships quadrupling in size and fleet tonnage. Nor has speed grown, at least for surface warships where 30 knots has been attainable for over a century. Change has been more in the means of achieving the ends, e.g. gas turbines, electric drive, or in configuration (helicopter landing decks, stealth geometries).

Paul Wrobel raises the question of Technology Push or Market Pull. There are examples of both, but as a broad generalisation, I suggest the former mostly applied up until about 1950 and thereafter the latter. In both cases today, the problem is who will commit the likely high development expenditure, as even if successful their investment may not be sufficiently protected by patents or manufacturing exclusivity. James Dyson had to spend huge sums both in developing his original vacuum cleaner designs and today in protecting his patents. Is the drive and incentive still there in the marine field (i.e. not a consumer mass market), at least for individuals? With so many businesses today having short term horizons; the money men will close down divisions without good prospects of profitability soon. More likely in future, it will be Regulatory Push, where demands for say ballast water treatment creates an automatic market for equipment, so companies may be prepared to invest in R&D. Regulations like the Energy Efficiency Design Index focussing somewhat simplistically on performance per tonne-mile seem likely to put a brake on speed increases, since the easiest way to attain required figures will be to reduce speed and hence power and emissions. But speed cannot drop too far, if installed power then becomes too low to provide the thrust to overcome added resistance in adverse conditions. A problem here is whether the regulators set cost-effective levels of attainment, especially when the necessary technology may not yet exist. Both costs and benefits may be rough estimates at best, while the law of unintended consequences is universal. This is a reason for applying any new standards in gradual stages. Not only can the effectiveness be monitored to achieve an optimum, but there is less incentive for regulation cheaters.

Somewhat related is **Tim Macdonald’s** discussion asking how successful technologies were driven. In the past, some were driven by individuals of private means

(Froude with towing tanks, Parsons with steam turbines). That is a less likely model today, although perhaps Dyson is an honourable exception. But corporate need can still be a driver to new concepts, e.g. containerisation in the 1960s to get over the problem of slow and expensive general cargo handling. In such cases, the potential gains were large enough to create the will to solve the engineering and organisational problems. Perhaps a modern parallel is the further development of natural gas as a marine fuel, at present in local vessels like ferries, but needing efficient bunkering systems worldwide.

David Andrews and **Charles Betts** note the importance of electronics, combat systems and their integration. Here modern naval vessels are quite unlike commercial vessels, or even WW2 warships. The latter went into service two weeks after delivery from the shipyard. Two years seems more common today, so clearly there is lot yet to be achieved to increase operational life. Then the question of unmanned ships. While there is indeed already potential for such in autonomous military vehicles (where risks to a human crew may be a major factor), for commercial vessels I do not think the unmanned ship is an attractive economic proposition, even if technically feasible. Crew number in commercial vessels can be reduced to single figures at a not unacceptable cost, but the cost of removing the last few from the crew down to zero will be immense, given the need for 24/7 operation (unlike other vehicles). As humans can not only keep a lookout for hazardous situations, but inspect and (temporarily) repair, it is possible to keep ships operating 6-7000 hours a year, something no other vehicle can do. Ground crews do most of the inspection and maintenance for aircraft or land vehicles, but that reduces annual operating hours. Taking the last crew members (minimum of three to work 24 hours) off the ship will require a huge investment in redundancy of systems, damage tolerant structures, monitoring and bypassing or backing up failing systems automatically, vastly more than the savings in crew and accommodation costs, yet with little potential gain in efficiency, to say nothing of the need for widespread marine traffic control systems.

Nick Pattison asks about more specialised ships. This has been a continuing trend from the first tankers 125 years ago, through to chemical carriers and car carriers today. Each is more efficient at their job, which usually outweighs the flexibility of a general purpose ship. I see no change in this trend. As long as cargoes move in sufficient volume on a trade route to justify specialist ships, they will be developed. But for warships it seems different. With budgetary pressures resulting in navies having ever fewer ships, either roles have to be given up or multipurpose vessels developed – but weapons and crews need to be matched to such. Achieving the right balance in multi role ships is an almost impossible problem – the features needed for a conflict today may be quite different in 10 or 20 year's time. In principle multi criteria decision making systems can help solve such problems but only if the decision maker can decide the relative importance of each role – and he may not be around to justify his decisions when put to the test. In theory therefore short life ships should be designed, with each new model more tuned to current demands, as happens with cars. But like those older cars surviving decades in third world countries, so obsolescent but operable warships will find a home somewhere. But with higher quality materials (including coatings) and more reliable machinery and equipment, longer life will become more achievable in merchant ships without a built-in payload, if the basic demand does not change, e.g. oil tankers, or if the regulators do not force them out.

Charles Betts comments about leisure craft features. Clearly as disposable incomes rise and the market for such craft remains competitive, existing high-tech trends can only be reinforced.

Chris Dicks and Charles Betts raise the question of lessons from history. The late David Brown wrote a paper for RINA in 1992 "History as a Design Tool". As a designer who was able to draw on historical (as well as personal) experience, he identified features of both successes and failures. In commercial service, economic pressures may have blurred the problems or not enough time was given over to exploring early the design and operational issues, e.g. large tanker structures in the 1960s, until damage or repair costs revealed unexpected problems. In the ro-ro case, there was a degree of complacency (surely no-one would ever leave the bow door open leaving port) until casualties showed that a greater degree of fail-safeness was required, e.g. double hull at sides, not just below the main deck but above. The comparatively high loss rate of (older) bulk carriers in the 1990s was partly inadequate design (insufficient attention paid to fatigue hot spots) and partly poor inspection and maintenance procedures overlooking weaknesses. These have now been corrected, e.g. by enhanced surveys and Common Structural Rules, and the loss rate reduced.

In such cases, it was not the basic concept that was flawed (although there were attempts to ban ro-ro's altogether) but the detailed engineering. In the case of HTP in submarines, at the time it was developed (by the Germans in WW2) it looked to be a way of increasing power, speed and endurance. A parallel case was the free piston gasifier in the 1950s that required too much development to make reliable. But in both cases, they were soon overtaken by superior technology: nuclear propulsion in submarines, compact geared medium speed diesels in merchant ships. So not so much a 'mistake' but a warning to be on the lookout for better engineering solutions when the current one might create difficulties. One could argue that such stemmed from the general lack of prototype testing in the marine industries, at least when compared with the aircraft industry.

Chris Dicks also mentions teaching of (marine technology) history to young naval architects. I am not aware of any formal courses in UK universities, one problem being that engineering degree courses already have hugely more contact hours for students than most other degree courses. Students may only use half of what they are taught in their future careers, but it is a different half for every student, so pruning is risky. Some will need to be able to apply Chris Dick's 'complex technologies', so all students need an appreciation of them even if they may not become practitioners. When I was lecturing full time at Newcastle University, I made a point of including a few such lectures in one of my courses. In my current part time teaching of marine transport courses, I always include a historical perspective to help draw parallels giving examples, and the whys and wherefores. If you can understand why things developed and the impact they had on the ship or the business, you are better able to judge where future advances might be made. The past is the only guide we have to the future, so it is useful to be aware of successes and failures and long term trends. In the past with stable organisations and career structures, that could be learned by 'osmosis' from the 'old hands' and the corporate memory, especially in the field of warship design. There does not seem to be a modern equivalent mechanism given today's short job spans, so each naval architect has to build up his own experience as best he can, which in the past was recorded in his private 'little black book'.

A long term perspective suggests three stages of development: technical, economic then social. In each case at any point in time, current standards of attainment may seem modest, but are gradually improved until the law of diminishing returns sets in – the flattening of the curve – achieving some sort of asymptote around some realistically achievable level. For example, early steam propulsion systems had very low levels of thermal efficiency, but coal was cheap and the steamship could do things that sailing ships could not. Gradually the technology improved, e.g. from better materials for boilers and expansion from higher steam pressures, until steam system efficiency levelled off. In due course the economics, say of rising fuel prices, pushed out the less efficient technical designs, e.g. steam turbines in the 1970s. Now it is social acceptability that is the driver, e.g. demanding safer ships and lower emissions. Hopefully such can be achieved without jeopardising the real gains that have been achieved in technical and economic efficiency. The solution to the recent Gulf of Mexico blow-out and oil spill is not to ban offshore drilling (the resource of offshore oil is too important to be neglected) but to develop the technology and operating procedures to do it better and more safely. That means that somehow the engineers have to educate politicians and members of the public of the right direction to go, a difficult task given the generally poor understanding of science and technology in many western societies. While all appreciate the convenience of electric power, few seem have any appreciation of how it can be generated, and how other forms of energy are needed to propel most vehicles, leading to a generally uninformed level of debate about say renewable energy sources and transmission, which increases the likelihood of wrong decisions being made.

Chris Dicks asks if the role of the naval architect will change. I do not think so fundamentally, as he/she is always concerned with the triad of Design, Construction and Operation. The naval architect will remain the general practitioner of the marine technology business, needing a broad general knowledge and recognising when to call in the specialist, akin to the medics. The specialist cannot be expected to be aware of the overall picture or take responsibility for the total design concept. But acquiring that general knowledge and experience remains a challenge for every individual. When I started in the profession, most naval architects worked in shipyards and envied the Royal Corps of Naval Constructors for their well-rounded education and training programme. Today, although there are many more naval architects (at Newcastle the number graduating each year is up around fivefold), most in the UK at least work for design houses/consultants or classification societies (see The Naval Architect October 2010). There is no reason why naval architects (or marine engineers) cannot undertake the management of projects that Nick Pattison comments on. I have never believed that a 'manager' can manage anything without a deep understanding of what the business is all about. But perhaps the successful ones are in such demand as not to have the time to expound on what makes for success. Accountability is essential; in how many major failed projects have the individuals responsible even been identified, let alone the real causes? But case studies (with no holds barred) can form a valuable learning experience.

A key social issue that has yet to be addressed is how to man increasingly complex ships with well trained and experienced personnel. In better off societies, few young people want to go to sea or do not stay there long given the attractions of a shore-based job (and wife?). Few people in such societies have a seafarer in the family or have ever met one. There are no votes in ship users, unlike motorists, so understandably politicians ignore the issues or see shipping as an easy target on which to burnish their environmental credentials. If a marine disaster strikes, there are often unthinking knee-jerk reactions, e.g. refusing a safe refuge for the stricken tanker Prestige in 2002. What will be the outcome of Costa Concordia's grounding, a clear case of human error? Even the specialist documentary TV channels which show say container shipping or offshore operations have a breathless commentary about the impending disasters lurking round every corner, rather than the benefits bestowed on humanity. There are no comparable manning problems for aircraft, who do not seek most of their personnel from cheap third world countries with little training. Some imaginative thinking about how to man and operate the ships of the future is long overdue, given the demanding nature of ships and their payloads.

Those considerations influenced the final paragraph of my paper, but perhaps explains more of my reasoning behind the sentence “So perhaps what the marine industries need in the next decades is to focus enabling technologies on getting the best out of well-established concepts like steel hulls and internal combustion engines by improving reliability, operational efficiency and mitigating the safety and environmental impacts of ships, but without jeopardising the technical and economic gains of the last 150 years.”

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