DISCUSSION

150 YEARS OF SHIP DESIGN

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COMMENT

C Dicks, Fleet Constructor, Navy Command HQ, UK

I should like to thank Professor Andrews, 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 would also ask Prof. Andrews to consider appending a further S to his S^5 teaching tool to recognise the prominence of safety as a discipline. Naval Architects spend increasing amounts of their time on this discipline, especially the risk based safety case culture which has become such an integral part of naval ship design evolution that the Commanding Officer of a new RN ship should not operate it without a thorough understanding of his safety case. Developing the safety case requires a broad understanding of the use of the vessel and wider disciplines such as seamanship, as well as the underlying technical analysis, for example when assessing risk to a human during submarine to boat transfer. This fits nicely with the wider role of Naval Architects as the ship integration lead.

I find myself reading this paper, and that by Professor Buxton, 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 of 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 authors consider this course a useful addition to the core curriculum?

By the appearance of their papers in the Trans. RINA, Professors Buxton and Andrews 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.

I Buxton, FRINA

David Andrews has given us a comprehensive review of the evolution of ship design over 150 years, well divided into both chronological and subject sections. As noted, there were generally few INA papers addressing the rationale of design or designs, which may have been a result of designers unwilling to part with hard-earned information. This was less the case with the regional engineering institutions. Perhaps this was because apart from the Admiralty (DNC Department based in London until 1940) most actual ship design was carried out in shipyards concentrated in the north of England and in Scotland, after the decline of Thames shipyards from about 1870. Design papers were regularly presented and

attracted large local audiences. For example Robert Thompson's Presidential Address to the North East Coast Institution of Engineers and Shipbuilders in 1892 was full of technical data, while Harry Bocler's paper on ballasting of ships to the same institution in 1942 was likewise practical – he was the naval architect at Swan Hunter & Wigham Richardson. At the Marine Technology Special Collection at Newcastle University we have all of Bocler's detailed notebooks in which he recorded his data and experience – the traditional naval architect's 'little black book' writ large in a dozen red notebooks. In the similar Institution of Engineers and Shipbuilders in Scotland, David Watson's classic paper on estimating ship dimensions in 1961 (updated by him and Gilfillan to RINA in 1977) was a godsend to naval architects young and old – Watson was then the naval architect at Alexander Stephen.

Throughout the period, the naval architect has remained the general practitioner of the marine technology business, like his medical counterpart needing to consider the whole body and knowing when to call in the specialist. Today specialists are routinely involved in the design process, e.g. propeller designers or noise and vibration experts. But it was not always so – I recall being surprised to be told by a retired marine engine builder that they routinely designed and manufactured propellers for shipbuilders with virtually no reference to the associated hull. At least that practice kept purveyors of patent propeller designs in business, who would often be called in by shipowners dissatisfied with the seagoing performance of their new ship. The solution was not in fancy blade geometry but in better matching of propeller characteristics to the actual hull and engine.

Indeed predictability of performance at the design stage has been one of the ongoing design improvements – today it is rare for a ship not to meet its contract requirements. This has been partly due to improving the 'how' of ship design. Much less lengthy manual calculation, much more sophisticated design aids. How the naval architects of the 1880s welcomed the Amsler integrator to greatly speed up calculation of cross curves of stability, while in modern memory, the replacement of tedious hand calculations of damage stability with computer programs allowed the designer to readily explore much more complex patterns of damage cases and different subdivision.

Fortunately the introduction of the digital computer in the late 1950s coincided with the rapid expansion of ship types and sizes. It soon drove out the mechanical calculator for calculations like hydrostatics, while every naval architect bought a personal calculator in the 1970s. In only 20 years tankers grew from 30,000 to 300,000 tons deadweight, while new types such as container ships, bulk carriers, roll-on/roll-off ships, cruise ships and liquefied gas carriers were introduced. Designers were enabled to assess the complexities of these new ships – finite element analysis for large tanker and container ship structures, damage stability for ro-ros, ship motions for cruise ships. But these were only methods of analysis – the designer still had to synthesise, that is propose the features of the new design from the metaphorical 'clean sheet of paper', and here experience and corporate memory still had a part to play in proposing a plausible design for the software to analyse.

The design authority has changed over the years for different ship types between shipowner, consultant and shipbuilder, with no definitive answer to what is best. Especially with fairly infrequent newbuilding, there is a problem with an owner maintaining an 'informed customer' status, with frequent staff turnover in modern organisations and the rise of the project manager who may have little first-hand subject or intuitive knowledge. Many major merchant shipowners who used to have a naval architect's department now rely on technical superintendents, which has allowed the shipbuilder to become the design authority, especially in seller's markets. Interestingly one of the few owner types to have maintained such expertise are those with the greatest technical and commercial successes in recent years, namely cruise ships.

Not surprisingly design and order-to-delivery times have greatly increased over the years, partly due to ever increasing complexity but also to ever more demanding regulations to be satisfied. A hundred plus years ago, ships would be routinely ordered, designed and delivered in less than 12 months. Maybe not a fair comparison, but contrast that with the UK's two new aircraft carriers, whose design started about 1992 and are unlikely to be completed before 2017 – 25 years, which is a normal ship's lifetime. Design costs have increased as a percentage of construction cost, but still remain modest compared with some other complex engineering artefacts.

In addition to the author's design issues 5 S's – Speed, Stability, Strength, Seakeeping and Style – I added seven more in my lectures to first year student naval architects, some more applicable to merchant ships than naval, e.g. *Size* – there is an optimal size of ship for each trade. *Shape* addresses hull form more explicitly than Style. *Stowage* is crucial at least for piecewise cargo like containers or wheeled cargo. *Systems* recognises that a ship is part of wider system, e.g. a transport network, as well as having sub-systems like cargo handling. *Seamen* gives the crew a formal place in the design process, both in operating the ship and it being their home. *Safety* - one could argue that this is implicit in things like Stability, but in today's increasingly regulated world, it needs to be addressed explicitly. The twelfth for commercial vessels is *Solvency* - I could not think of another S word that implied achieving a satisfactory financial return. Perhaps for military vessels *Stealth* or *Signatures* could be added.

A small but welcome change in design papers presented to RINA is recognition of all the contributing authors by

name. The traditional DNC authored paper is mentioned, but his staff, who researched and wrote the bulk of the paper for the great man to polish and present, rarely got a mention. In today's busy professional world, these latter rarely have the time to prepare papers on design, while their employers are less willing to disclose technical or commercial information. The effect has been that many naval architectural papers tend to be by academics and research students, all worthy but driven as much by 'publish or perish' as a desire to inform the profession, which has always been a key role of RINA.

C V Betts, FRINA, FREng, RCNC:

This paper is an excellent, thoughtful and valuable successor to Barnaby's Centenary paper. It is particularly useful to have a full review of the Institution's past papers on ship design as such, enhanced by the author's considered view on the future of ship design (a view with which I very much agree).

As the author says, it is a pity from the profession's point of view that national security considerations have prevented papers being presented on the design of nuclear submarines. Their design is among the most interesting and demanding of the challenges faced by naval architects and indeed by a number of other branches of engineering. The excellent 1984 paper by Paul Wrobel on the design of the Royal Navy's Type 2400 'conventional' patrol class submarine gave a good idea of the general design process for a submarine but obviously was not concerned with the major implications of incorporating a nuclear power plant in a submarine. There were rumours some 20 years ago that a paper on the design of a Royal Navy nuclear submarine class had been prepared and even given initial security clearance but final clearance must have been withheld as the paper was never published. I sought and obtained clearance for an extremely brief description of the design of the VANGUARD Class Trident nuclear ballistic missile submarines, together with a brief mention of the ASTUTE class nuclear submarines, in my 1998 paper "The Royal Corps of Naval Constructors Today", although fuller descriptions of some specific aspects of both designs have been published elsewhere. These days, of course, one can always refer to Wikipedia although accuracy should not be taken for granted!

The author makes an important general point about the Transactions of the Institution, embodied these days in the journals IJME and IJSCT. He points out that these no longer constitute the main source of technical papers on the practice of ship design. RINA itself does publish many papers on ship design but the great majority of these are published and marketed separately in the proceedings of the many excellent conferences and symposia sponsored by the Institution. One can, of course, identify and if desired order all such papers via the web. However, this is not nearly as convenient as in the past when all RINA papers were available in one set of annual Transactions. With the welcome explosion in the number of papers, that is clearly no longer practical. Yet busy naval architects, designers in particular, may not always have the time to trawl the extensive RINA website for papers that might be of use to them. However, I do note that conference/symposia papers considered to be of particular interest and merit are occasionally republished in The Naval Architect. As an extension of this process, I would like to suggest that a selection of the most valuable papers on ship design given at RINA conferences and symposia be reproduced in the Transactions. Selection could be a matter for the Publications Committee, as an extension of the role they already have for deciding on potential candidates for Institution prizes. The author's views on the sense, benefits and practicalities of this proposal would be welcome.

J J Hopman, Delft University of Technology, Netherlands

I would like to congratulate David Andrews with his efforts to make a comprehensive overview of 150 years of developments in ship design. Although only based on the articles published in the RINA Transactions during this period it still provides a very good reading guide for a new generation of young naval architects who are interested in their roots. By highlighting certain developments and subjects presented in these 150 years and by categorizing these for the last 50 years in 7 different themes makes it easier to see how the view of ship design has changed.

I am missing, however, the 8th theme in his paper: the role of the naval architect. The position of the naval architect within the design team and his skills needed for successful ship design have changed a lot during the last 50 years due to the increase in number of different disciplines involved and in complexity of designs. Related to this is the increased need and interest in on how to manage these complex projects.

N Pattison, BAE Systems Surface Ships, UK

I would like to congratulate the author on an excellent paper which I found to be a very useful review of those papers and articles within the Transactions which relate to ship design. The coverage of papers published between 1860 and 1960 is a valuable distillation of the developments and designs generated during a period which is, I suspect, little understood and little appreciated by most Naval Architects practising today. The more in-depth assessment of the past 50 years is equally, if not more, instructive.

The author makes the point that ships "remain the largest manmade mobile environments" and this is an observation I whole heartedly agree with and together with the fact that so many ships "are bespoke" suggests to me that the enterprise of designing and building ships

is still one of the most demanding design and engineering challenges which organisations undertake. I have often thought that, together with the significant complexity of many ship design and build projects, the high levels of uncertainty which pervade a typical such project result in a quite uniquely demanding industry. I would be interested in the author's views about how uncertainty influences our projects and what fundamental factors drive it. For me, factors such as small batch sizes and the low frequency of projects have a critical influence on how the business works, or can work.

The variety of ship types covered in the papers produced since 1960 is quite bewildering, ranging as it does from aircraft carriers and cruise ships to fishing vessels and lifeboats. Furthermore, the range of topics dealt with; accommodation, escape, fluid dynamics, Computer Aided Design, ambiguity, etc. etc. etc. illustrate the vast number of influences on the design and construction of our products. One topic which seems a little underrepresented in the paper is that of the management of our projects. I am aware that approaches to managing ship design and build projects vary significantly from sector to sector and no doubt from nation to nation. Does the author believe that more papers on this topic would benefit the industry?

T P McDonald, University College London, UK

I would like to thank Professor Andrews for presenting a succinct paper describing the varied ship design related articles, published by the Institution over the last 150 years, and their contributions to developing the field of ship design research. I am currently completing a PhD focused upon this field (and must declare that Professor Andrews has acted as one of my supervisors). I feel this paper provides an important contribution as it tracks the field's historical development. I was interested to note the progression from the early papers presenting and summarising novel designs, via the papers exploring specific design issues, to the more recent papers highlighting different design techniques, methods and approaches.

I hope that the inclusion of Andrews and Pawling's 2008 paper detailing "A Case Study in Preliminary Ship Design" provides an indication of a possible new direction for the next 50 years; encouraging those proposing different design approaches to better describe how their approach is applied and hence develop links back to specific design issues and, therefore, promoting the development of improved design solutions. I am confident that other authors will take up the challenge of producing similar work in the future.

Finally, I would like to end by asking Professor Andrews where does he (as an individual whose career has spanned both academia and industry/government projects) see that the primary effort lies in ensuring tomorrow's naval architects acquire both more creativity and a broad knowledge base?

AUTHORS' RESPONSE

Constructor Commander Dicks has posed three very significant questions to both myself and Dr Buxton, as author of the companion "150th" paper. I will endeavour to answer them from the ship design perspective.

The first question is on the changing role of the naval architect and whether we are appropriately preparing naval architects for it. Cdr Dicks is sceptical on the emphasis devoted to complex analysis and suggests greater focus on design theory and practice. The issue of complex analysis seems to me to be two fold: there is a need for a professional naval architect to understand the core theory and assumptions in methods like FEM and CFD so that they both use them appropriately themselves and can sensible interrogate result produced by deeper experts; secondly, it is awareness of the underlying theory behind "advanced topics", such as probabilistic methods applied to ship strength and seakeeping, with knowledge of (say) manoeuvring theory and lifting line methods that mean the ship designer is more than a mere technician applying codes and accepting others use of advanced methods. This is the basis of the "extra knowledge and skills" acquired in a typical MEng or MSc, above and beyond the basic BEng. Acquiring design skills is primarily a heuristic process, with some background theory in general and on ship design issues and methods. That background is best conveyed by cycling through, as temporary course staff, ship design practitioners rather than pure theoreticians, an approach which both the US Navy and the UK "naval naval architects" adopt at M.I.T and UCL, respectively. The heuristic element, learnt through a plausibly realistic ship design exercise and overseen by the "seconded" practitioners, both exposes the young naval architects to the challenge of complex design and enables some of their recently acquired skills in complex analysis to be applied to their burgeoning designs. Whether this noticeably expensive overhead can be applied to the generality of advanced naval architecture courses depends, possibly, on both adopting (in the UK) the Royal Academy of Engineering's Visiting Professorship scheme (www.raeng.org) and finding practitioners prepared to make a significant annual commitment, when the pool of such expertise is frightening diminishing. Technology development skills, by which I presume Cdr Dicks means those of a more managerial or systems engineering nature, can only be introduced in such a course but are more readily acquired as part of continual learning/CPD, which is going to become more necessary in a globally competitive career environment.

The issue of further "S"s to "S^5" has been raised before, with Survivability, Sustainability, Supportability, Signatures (and indeed further merchant ship relevant "S"s by **Dr Buxton** in his comments) as well as Safety being suggested. I think this misses the essential difference between Style and the first four Ss. The latter are essentially the traditional sub-disciplines of the

engineering sciences which naval architects, as dare one say "hull engineers", are responsible for in ship design, whereas Style is something different. I have tried to list the main topics I consider this term covers, as broader issues that are relevant to the naval architect in his role as the ship design architect and engineer (analogous to a mix of the built environment's architect AND the civil engineer). Naval architectural education has not addressed these issues in the same depth as the "first four Ss" for good reasons and cannot yet devote much more effort to them. However, it may be that more than just an awareness of some relevant theory and tools, associated with, for example, human factors aspects, may start to be incorporated in the typical Masters' level ship design exercises. I have propounded this need for expanding the ship designer's knowledge base as a logical consequence, I believe, of the necessity of the opening up preliminary ship design, which itself arises with the adoption of the UCL Design Building Block approach, referred to in the third paragraph of Section 4.7 of the paper.

I support Cdr Dicks' suggestion that, separately from the need for new areas of knowledge, the history of ship design should also be incorporated in maritime engineering courses. We have, in the field of ship design, D K Brown's strong plea to that effect in his 1993 paper, also referred to in Section 4.7, and furthermore I recall his strong injunction to "remember the HUNTS" as a salutary lesson of what can all too readily occur when a design organisation fails to maintain independent design checks, even in the throws of a war of survival [6]. There is also no reason why historic lessons cannot be introduced into the body of general teaching, such as referring to casebook examples like "*Vasa*", "*Captain*", "*Titanic"* and *"Estonia"* when introducing topics in ship stability. Whether UK engineering courses as a whole should have a larger element of general education, such as philosophy and general economics, which are core to the French Ecole Polytechique's curriculum, raises a question well worth a wider debate, particularly if one believes the British Engineer lacks commensurate influence and status *vis a vis* his or her Continental cousin?

This leads nicely onto Cdr Dicks proposal that a (eminent and media savvy) submarine designer presents submarine design to the next available Royal Institution Christmas Lecture series. It is a topic that would certainly show the intellectual challenge in designing an excellent example of a Physically Large and Complex System [7]. I would not dismiss the idea for security reasons, as both the short UCL Post-Graduate Submarine Design Course (www.mecheng.ucl.ac.uk/learning/short-courses/submarine-design/) and the text book by the late Roy Burcher and Louis Rydill [8] show this can be side stepped. However an alternative might be "Design in the Age of the Computer" with ship (and submarine) design (as PL&C System Design *par excellence*) at the apogee, rather than aerospace or software – 'though, I am sure, both could be included *en passant*.

Dr Buxton's comments add immensely to the value of the paper, especially his insight that the sister institutions in the North East of England and Scotland have more readily provided design details than generally occur in the Transaction papers. The naval equivalent of Bocler's note book were those of the many naval constructors, which still provide real design details but only once they have been declassified and held by the National Maritime Museum at Woolwich. I am grateful also to his description of the essential synthesising role of the naval architect starting with the metaphorical blank sheet of paper. His pertinent observation is that Design Authority in the merchant ship field has tended to be retained at the top end of the complexity spectrum. Interestingly in the naval domain the issue of transfer from the owner has been addressed by Dr Gates in his 2006 paper (see Section 4.7) although it now seems to be returning back to the naval owner, the UK MoD, for similar reasons. However such moves are only sustainable if such "owners' are prepared to employ sufficient properly educated and experienced ship designers. It is not just in defence that the consequences of not doing so can be seen for the tax payer (see the Audit Commission's critique of the Antarctic Survey's purchase of the *James Clark Ross* over a decade ago [9]).

I feel, as the project manager who started the original design studies for the new *Queen Elisabeth Class* aircraft carriers in 1992, that I must comment on Dr Buxton's remark on the length of the naval ship design process. Of course naval ships are different – they are not driven by commercial necessity to get a more commercially efficient product into service as soon as possible. Such an imperative, outside a clear threat of major hostilities, only arises in naval ship design if a brand new feature must be got to sea (for example the Type 45 weapon system - due to its predecessor's obsolescence - or the Type 23's significantly new sonar capability). Otherwise the need is to meet wider imperatives of government, which in the case of the *QE Class* seem to be both to preserve the national naval shipbuilding capability and to have carriers available once the appropriate aircraft are in service. This stretching out of a construction programme is not unique to the UK, France did the same in the 1990s with its Porte Avion *Charles de Gaulle.* Fiscally it means the individual total programme costs are more, but expenditure less annually; the latter being attractive to the Treasury, if not the navy. This has little to do with design timescales, 'though sometime the major steps in decision making are prolonged for similar current fiscal imperatives.

Dr Buxton's final comment on welcoming recent design papers being presented by the "true authors" is valid to a degree, and as the junior author of the 1980 Transaction paper on *Invincible Class* (see Section 4.3), co-authored with the late Arthur Honnor then the Project Director, I greatly appreciated the recognition of my authorship. However, the old practice that every RN design was presented to the Institution by the DNC was, in no small

part, a recognition that the DNC was personally ultimately responsible for all the designs on his watch. He would have signed off the design, by closely scrutinising the Book of Calculations, and as the Technical Advisor to the Board of Admiralty was the true Design Authority. With the loss of that role, the demise of Books of Calcs and, indeed, Ship's Covers and with much now delegated to contractors, one can just hope modern processes of Safety Case assurance, at least, provide an audit trail.

I am very delighted the paper has **Mr Betts'** endorsement, though I don't feel my design specific review could match Barnaby's summary of the full range of the first century of Transaction papers. On the specific issue of submarine papers, several key papers were published in the early "Warship" conferences from the first in 1983 [10]. Interestingly, these included Harry Jackson's paper on *USS Albacore* [11], showing US Navy's preparedness to publish in significant detail, having been matched in this regard by the seminal SNAME paper of 1960 by Aretzen and Mandel [12]. Mr Betts also asks for my view on his proposal that the best papers from appropriate Institution conferences be published in the journal and the Transactions. In principle this was the intention behind the award of the David Goodrich Prize for the best paper at the annual RINA "Warship" conference, however there is sometimes the desirability for papers, which may be written for a very specific conference audience, to be modified to make them more appropriate for the wider Institution. However, I cannot see that this should apply to descriptive papers on specific ship designs, which, as I comment at Section 4.3, now tend to be presented to conferences rather than to the wider profession through the Transactions – so the authors of such papers need to be encouraged to also submit them to the journal (and Transactions), thereby enabling the profession to then debate such designs in written discussions such as this.

Professor Hopman and **Mr Pattison** both raise the issue of management in ship design – which I think, belatedly, now has a forum, with the intention that the first conference on Systems Engineering in Marine Design, held in October 2010, will be followed by further conferences on SE. I would also refer younger readers, in this regard, to the author's 1993 Transaction paper on the management of warship design (see Section 4.7 last paragraph). This was written from the perspective of a UK MoD Warship Project Manager in the late 1980s, so one can hope one of my successors, in the UK MoD or industry, might be prepared to present an updated view.

Mr Pattison also raises the issue of high levels of uncertainty typifying naval design projects, Such projects usually evolve in a difficult "political" environment and this has always seemed to be the case – one has only to think of the circumstances of the Swedish *Vasa* in the 17th Century and the more recent UK "Short Fat Ship" saga. The other main issue for naval procurement is that of Requirement Elucidation, for what remains a classic "wicked problem" in design methodology terms [13]. Mr Pattison also identifies further pertinent issues of low batch size, which in part leads to not having a prototype, and, increasingly, the low frequency of project ordering and completions, which means every design is different and has more and more expectations placed upon it. This also means each completed design having to incorporate the latest technologies and standards, while somehow so doing with reduced procurement and through life ownership costs.

I would also like to thank **Dr McDonald** for his comments and for drawing readers' attention to the 2008 paper I authored with Dr Pawling (see Section 4.7). I considered that to be a seminal paper in that we described, I believe for the first time in open literature, not just a given concept design but also the various intermediate design solutions and the important choices taken for each one, in evolving a final concept design. That paper also provides any historian of recent design practice with a comprehensive list of references on the nature of preliminary ship design, going beyond those highlighted in this review of the RINA Transactions papers.

Dr McDonald also raises the issue as to how ship designers might acquire a greater level of creativity as well as a broad knowledge basis. Clearly the latter is part of achieving the former, however I also consider there is a vital issue if both academia and industry are to foster a creative approach to future ship design. Namely, in producing new design methods and tools to execute such approaches, it is essential that neither aspect inhibits a creative exploration in preliminary design. Fundamentally this means avoiding "black box" approaches, which are too often produced in CAD systems with no explanation of the particular system's constraints and limitations. If designers are to be encouraged to explore widely (as was clearly the motivation behind Dr McDonald's successful PhD [14]) then approaches such as the author's DBB approach, which synthesises the configuration in 3-Dimensions, foster an essentially creative design philosophy. Such a visually based and designer driven approach further encourages a creative design exploration. This then becomes a basis for making design choices from as wide an investigation of potential options as possible.

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