HISTORICAL LESSONS AND TEACHING DESIGN

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Using all the available facts, from history when properly analyzed, can be of great value in teaching tomorrow's designers. The way in which decisions were made and the success or failure of those decisions in service can be a guide for the future. Methods of analysis can be demonstrated against past events, particularly disasters. Students can see trend curves as the codification of the past, helping them to realize trend curves potential and limits. Finally, there are benefits of pointing out past errors if only to keep from repeating them or reinventing the wheel.

Ships are among the most complex systems created by man. Ship design is a creative activity, the development of an integrated system using data from previous designs and tools of varying degrees of sophistication. Advanced technology is or should be reflected in the designers' tools and in his designs. Currently most authors looking at the future of ship design activity focusing on the impacts of advanced technology (1) or total systems approaches (2), few, if any focus on the designer, the most important element in the process. These visions of the future may become reality, but superior results will not result if the design team is not well trained or experienced in the process. In the hands of the poorly trained or inexperienced, the computer and data bases foreseen in the technical literature will produce poor designs as quickly as good ones.

Senior, well-respected members of my professional community, naval architecture, are worried about education and training (3,4). It is noteworthy that the Lisnyk Prize, the SNAME student design competition is being won by a wide margin by teams from overseas. The judges in these competitions have been troubled by the poor quality of many of the American design projects submitted. Gale, attributes this in part to the lack of professional practice by many who teach design courses. On-the-job trends are equally disturbing. In the past the best designers learned more on the job than in formal courses. Such on-the job learning used to come from junior's being mentored by experts critiquing their work. It also occurred when builders and operators provided feedback regarding deficiencies. For a multitude of reasons' designers today are not getting either of these kinds of feedback.

In my last assignment, I saw first hand the decline of this ability in the United States. An in-house design effort for a major ship program spanned almost twenty years and ended in failure. Shipbuilder's who finally offered proposals chose not to conducted their own engineering, but hired foreign firms (5). Part of this foreign expertise was for a state-of-the-art shipboard electrical power generation and propulsion system. The supplier was to be responsible for its performance. We found all of the engineering expertise for these systems overseas. US companies where only the representatives of overseas firms who conducted all the design and engineering work.

Why is this occurring? There are many reasons. One is the decreasing frequency with which ship design is undertaken in this country. Table 1 gives an indication of the scope of the problem. Ship design and construction programs are beginning to span periods half the working life of an engineer. Another, is our professional organization, new design is a very small fraction of the work load. The reward system is also an important factor. Young engineers seem to be rewarded more for their management then engineering skills. Many, excellent engineering college curriculum lack courses in systems engineering and design integration. Graduates therefore, receive little training in the development of the skills needed to be a member of a multi-disciplinary design team, conducting design tradeoffs, consider factors such as cost, or operational use. There is little research in such areas and few papers on this subject are published. My feeling is that Engineering departments are more likely to view such skills as a soft science and the proper domain of management departments. How do we overcome these trends?

Class	Ship Type	Number Built	Construction Started (Year)	Years Built
Norfolk	Cruiser	1	47	5
Mitscher	Destroyer	4	48	6
Dealey	Frigate	18	51	7
Forrest Sherman	Destroyer	13	52	9
Leahy	Cruiser	9	56	6
Belknap	Cruiser	9	57	6
Farragut	Destroyer	10	57	7
Claud Jones	Frigate	4	57	4
Adams	Destroyer	23	58	9
Bronstein	Frigate	2	60	4
Garcia	Frigate	10	61	6
Knox's	Frigate	47	64	10
Spruance	Destroyer	30	70	13
Perry	Frigate	55	73	16
Ticonderoga	Cruiser	27	79	15
Arleigh Burke	Destroyer	29+	85	?

TABLE 1: SURFACE WARSHIP CONSTRUCTION 1948 -- 1997

The fundamental nature of design has changed little, "to conceive from a figment of imagination through the aid of science to a plan on paper"(6). But, what is good design and how is it biased by the viewer? The designer may see it as cost effective solutions to the design requirements, ignoring the failings in requirements. The historian's whom the designer looks to for guidance, may give more importance to the later life of a system when it was obsolete and used in missions not contemplated in the design. The crew, may attach more importance to aesthetics or to habitability then fitness for service. Which is right, or are they all?

The teaching of design and design management is not easy, in the past we could count on gaining experience as new designs were completed and vessels commissioned almost every year. In the twenties and thirties, new classes of warships were started every few years and design studies were conducted every year. In the US Navy such studies were described as the “spring styles”(7). During this time period a designer would have worked on and received feedback on several classes before being responsible for one himself. He was backed by a technical staff having years of experience in similar ships. This is no longer the case as intervals between designs has continually increased, reducing the practitioner's experience.

Historically we represented the design process as a “design spiral” in which each topic is studied repeatedly in increasing detail in the search for a solution. A design spiral is a one dimensional representation in which each topic is taken in turn. In reality each topic interacts with many others. These interactions often take the shape of closed loops, for example ship displacement can’t be estimated until power is known, but power depends on displacement. Each leg of these more simple loops are also legs on other loops. This web is resolved with databases, equipment requirements, the use of standards and experience. The solution to the above example on displacement and power is easy for a surface ship, collapsing from a decision that the installed machinery will be standard units and the speed will be whatever results.

This process is predicated on requirements. Most who teach design point out that requirements should be stated in functional terms, as an example, carry out fishery protection operations in an Exclusive Economic Zone. However, this is unrealistic in the real world; decisions made years earlier in other programs (command and control, machinery development, port facilities, etc.) have already preempted many decisions so the "requirement" inevitably consist of a mixture of functional statements and lists of specific equipments to be installed.

In these early stages of design, when most important decisions are made the problem becomes choosing one of a large number of design options. Such a choice is meaningless unless the requirements are understood by designer and user, which is usually not the case. Some are inferred as being "to previous practice" while others are clichés “to be a good sea boat," or the almost equally trivial “to maintain 20 knots in sea state 5." Defining a set of requirements is hard work. Good ones can help the design team and the operators understand the relationship between capabilities and cost. To be meaningful requirements should be stated as a probability of retaining a specific percentage of capability in given conditions. In life problems are not clearly cut and it’s necessary to indicate whether a required level is to be reached but not exceeded, a minimum level that should be improved on if possible, or an aspiration, unlikely to be attained, but approached as closely as possible. To a great extent this helps define cost.

Computer aided design affect these problems. It can be used to evaluate intuitive solutions, or to explore the significance of interactions. Used blindly, current systems ignore interactions and take default values along a one dimensional path. This is not the fault of the system but of an ill educated designer. Most CAD systems are built on a considerable amount of relevant data that can be used to create trend curves appropriate to a new design. However, this data is far from ready availability, being buried in the system, and any design in the database is far from being perfect. We should however, encourage the analysis of system data for its applicability and the search for other, relevant data when design approaches the edge of historical experience.(8)

There still are a considerable number of major interactions for which current programs provide little help. These are mainly in arrangement. Such problems include the link, through uptakes and downtakes, between alternative machinery arrangement and layouts. There are many interactions with layout, particularly safety and survivability issues such as duplication and separation. The right arrangements can improve operational effectiveness, and reduce costs. Yet few new engineer's seem to see the importance of "architecture" to solution of the problem, so it tends to be ignored.

The risk in using standards which are codified experience is another ignored area. Young engineers often take the last specification and follow it, without conscious decision. If the previous ship was successful, and the operator has not complained, just do what you have done in the past. This is a reasonable approach if the designer understands the foundations of the standard. Other important requirements remain more difficult to define, especially when they become part of a contract. It is not reasonable to require a ship to be free of corrosion for twenty years or for a coating system to last ten years. The more detailed, but important, requirement "to avoid rust traps" is contractually meaningless. Examples, such as making the builder responsible for life cycle maintenance seem doomed to fail, but continue to be in specifications.

Some standards, if applied too rigidly, may lead to considerable cost. For example, built in service growth for electric demand that exceeds a given valve, even by a small amount, requires more generating capacity, larger support equipment, etc., all at an increase cost. We need to teach that such rules are for guidance, not to be taken as gospel.

It seems necessary to review past lessons not only to avoid catastrophic mistakes, but to avoid reinventing the wheel. Analysis of past examples can aid teaching provided we understand both the historical and technical issues. It isn't sufficient for example to state that a margin plate should be thicker, the reason needs to be explained as well or such rules will be dropped for economy of production. The failures to record the reasons for design rules, often the lesson of an early disaster probably helps account for the reasons we seem to relearn them(9). Such lessons lend themselves to case studies. For example, in adopting new methods' designers try using proven details, because safety criteria tend to be based on experience. Radical changes tend to be reviewed with great care, and students can be shown disaster analysis as a way to impress these lessons on students. For example, while often looked at as a revolutionary, Admiral Rickover adopted an evolutionary philosophy in the design of the first nuclear submarine Nautilus. The reactor plant was the only novel feature. The propulsion plant was conventional, the hull even retained the twin screw form despite the success of the Albacore, the tear drop hull shape with a single screw. As a result nuclear powered submarines went to sea with few problems.

Design criterion is not absolute and is often based on the examination of past causalities. The most obvious examples are the changes in passenger ship subdivision and lifesaving requirements after the loss of the Titanic and in fire protection after the loss of the Morro Castle. The loss of the Captain, lead to intact stability standards, and the loss of three destroyers in the Pacific in 1944 led to the formal ship stability criteria widely used throughout the world today(10). The structural failure of early Royal Navy destroyers caused the introduction of wave loading criteria for structural analysis(11). These lessons still hold true today.

It is easier to say what will lead to disaster then what is good enough, but what's good enough is the lower limit in design. The majority of British World War II destroyers did not meet the Sarchin and Goldberg weather criteria, yet operated for their lifetimes without loss from bad weather. Careful review showed that they only just failed to do so, and that in some situations only excellent seamanship prevented disaster(12). The work of the US Coast Guard in adopting the Ra'hola safety criteria for the offshore oil industry is an example of careful analysis of historical data to set limits(13).

Equally important is to impress the student with the life span of major system like ships. A service life of 20 years (some last 50) leads to 35 years from start of design studies until the last ship is scraped. Over that time missions change, tasks are altered and technology advances. Historical trends show it is unlikely there will be in kind replacement, so modernization will be required. In the past we just squeezed things in, usually at the expense of living space, limited only by stability or strength. Such methods are changing to space, in the right place and shape that controls future adaptability. Case studies for "stretching" ships can come from projects like the destroyer conversions of the 1960's or the Spruance program that evolved into two other classes of major combatants.

The ship design and acquisition strategies hopefully have the dual purposes of retaining control by ship operators over the determination of requirements and basic design features, while trying to reduce risk. The method followed, affects ship cost, and program schedule, the process can be broken down into four phases shown in Table 2. It is during the early stages that the opportunities to influence overall cost and performance are at their greatest. Considering experience the cost of a new ship can be changed by as much as 100% early in a program, the opportunity for changing cost drops significantly during each subsequent phase. How these requirements are developed also affects the outcome.

The US Navy for example starts with a study team including representatives of the Navy's operator, personnel, logistics, engineering and acquisition communities to develop performance requirements to meet needs. This team conducts trade off studies for major issues such as effectiveness, speed, survivability, etc. The results are then reflected in operational requirements that do not change.

Ship characteristics are established in house with continuous support from several design contractors. During the feasibility, preliminary and contract design phases trade off studies are conducted first of whole ship attributes (size, arrangements, etc.), then systems (propulsion) and subsystems). The contract package is then prepared for competitive procurement by the Navy with the support of the design agents. This contract package is developed so as to allow for a variety of competitively procured equipment's, space and weight is generally provided for the largest alternative equipment that may be procured. Relatively large construction margins are provided to ensure the ship as delivered will meet the performance estimated in the early stages of design since numerous change orders normally occur during the subsequent design and construction phases. Detailed design is conducted by a shipyard, which is not asked to warrantee design.

Phase	Purpose	Output
Pre-feasibility	Study effectiveness and cost of alternative solutions Trade off requirements	Requirements Document
Feasibility conceptual, and preliminary design	Optimize best solution	Ship characteristics and performance
Contract Design	Establish bases for contracting	Contract package w/specification
Detailed Design	Basis for construction	Ship construction drawings

TABLE 2 SHIP DESIGN PHASES

Comparative analysis, has shown foreign governments generally conducted what in the US would be considered to be an extended feasibility design phase under "in-house" control. These studies generally encompass the work normally conducted during the feasibility and conceptual design phases of the US design process. This effort generally includes a detailed set of arrangement plans and a top level specification. If the feasibility of the ship design is particularly sensitive to some particular feature or features, those features are studied to a level of detail to ensure the solution is valid. The results are then offered to one or more qualified shipyards as the basis for the development of competitive contract design packages. The contract design package is provided to the government for evaluation and award. Each package reflects a specific set of equipment, with appropriate space and weight budgets. Under this strategy only small margins are provided or needed. Few change orders are expected or allowed and ship performance which is defined in the shipyard's contract specification is warranted These methods when compared to current procedures have provided ideas to improve our processes.

This process inevitably becomes compromise and the only way to learn is to study how conflicting issues have been resolved in the past and to review the success and failure of those compromises. The best designers recognize the conflicts between cost and effectiveness and quantity and quality. Good examples include the interaction between individuals and groups in a design, not only describing new designs, but outlining and recording the reasons for decisions and describing the internal organization of the design organization. These examples show how design teams respond to pressures to incorporate new technologies and other equipment and at the same time reduce cost. For example, the US Navy Perry class guided missile frigate(14), and the Royal Navy Type 23 frigate(15) both started simple, but turned into major warships. Both these programs are well documented, the review of the technical evolution of these designs;

requirements, work statements, technical deliverables, and design history show procedures that caused and mitigated risk.

Even old examples hold lessons. The first iron warships and the battleship introduced little technology, but successfully combine several recent developments. Both caused rapid change making them quickly obsolescent. The CAPTAIN on the other hand was lost because of the difficulty in obtaining solutions for righting energy at large angles of heel by hand calculation (no longer a problem). It wasn't appreciated that it depended on freeboard, which had always been required in sailing ships for other reasons. It was therefore, seen as an operational vise technical matter. The use of such literature can emphasize those things that have the potential to cause problems or solve them. Hindsight always promotes clarity of vision.

Further, we all follow the laws of physics, study of how engineers come up with different solutions to the same problem can aid understanding. The British and US Navy created independent frigate designs to identical requirements and major equipments. Apparently minor differences in design standards, particularly in subdivision and in power generation, led to the US version displacing about 20 percent more (16). These solutions are both valid, but very different.

This also extends to ships in service, the method used for comparative analysis is well established and outlined (17, 18). This procedure involves the collection of data to make valid comparisons, not an easy task given conflicting published information. Using this information a "standard" set of design indices can be computed. The indices, in turn, are grouped into functional areas for identification of the most critical design parameters The consolidation of this data into trends can demonstrates parameters that are stressed in each design in order to meet each particular mission requirements

Setting out requirements for an optimum layout is difficult. The problem is that the more important aspects, such as easy to live in, or to keep clean, are almost impossible to specify. Detailing some aspects only give undue weight to such aspects and may lead to more important ones being neglected. In theory, work study techniques can be used on each function seeking the layout that permits the smallest crew. Such an approach is extremely demanding. However, reviewing past ship arrangements in light of there use over their life it is possible to make a number of statements to provide guidance in development of new arrangements or even attach relative importance to a number of such statements. Therefore, analyzing past design based on service experience seems to be an acceptable solution.

The explosion in the development and automation of analytical methods presents a responsibility to engineering educators, especially as methods become commercially available software in the hands of the inexperienced. Adequate understanding of design criteria does not equate with being able to run PC based programs. We, however, owe it to our students to introduce and make available modern design tools. One way is to use validation methods for instruction. Historical, well-documented full scale trails (which also include after action reports) can be used to demonstrate our design and analysis programs. The problems of structural discontinuities and sharp corners seem to recur in every design, while being well documented in 1946(20), 1964(21), and again in the late 1970's(22), these problems could be used as an introduction to structural analysis programs. Likewise, problems with ship motion and spray generation seem to recur every generation.

We also need to demonstrate the limitation of our tools. Naval architects are accustomed to thinking of design parameters as continuous and usually as linear. In the past this was justified, warships carried enough guns to be smeared into a smooth curve. Cargo ships where sized by the number of cargo hatches. Steam propulsion plants were designed individually to provide the exact power needed for the required speed. In modern ships, this is no longer true, there are one or two major weapon systems, containers are a standard size. In all ship types the propulsion plant consist of a small number of standard prime movers.

Such major discontinuities or steps are easy to see, but there are many others that, are less obvious, but have important impact on a design. For example, most piping systems algorithms are based on the total weight of a system as a function of ship size, usually length. This is justified by the long fore and aft run of piping. However, if the weight breakdown of such a system is considered the major part of the weight and cost, lies in the pumps. The total weight of the pumps is primarily a function of the number of zones (sections) into which the ship is divided, coupled with the decision on whether pumps are duplicated. Even big changes in the capacity of a single pump will have only a small effect on weight or cost; it is the number that matters. Zones are only a loose function of length and only the piping that is a small part of the weight of the whole system is a direct function of length.

Similar arguments apply to all fore and aft systems, but, the number of zones needed is only loosely related to the length of the ship. Safety and survivability are affected by moderate changes in the length of individual compartments. Design for minimum cost then becomes a matter of identifying all the step functions in parameters and designing just below them. This is a different design problem than the historical one.

The study of previous developments can help give the perspective that is necessary to appreciate the point at which we have arrived in ship evolution and the direction in which progress will go. A historical review does not consist merely of a listing of names figures, and dates. The objective is to give a critical discussion of ship and equipment types and to explain the causes; technical, economic or military, and political which influenced the evolution. Design and building programs, trials and disasters have lessons for the new and experienced designer. From an instructional point of view causalities, user feedback and naval actions are full scale tests, which can be used to help a student understand the design process and the use of new techniques.

In business or government, the construction of ships involves policy in choice and design. These problems require the deliberations and cooperation of many people with varied experience and points of view. The best results are attained when designers are familiar with existing policy not only in their own organization, but in others as well. Such knowledge at present is not easily acquired, it is scattered in sources, many of which are not readily accessible, or have unreliable information intermingled with authentic material. The labor of collecting, sifting and arranging the information to be useful in design is not easy and extends over a lifetime.

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