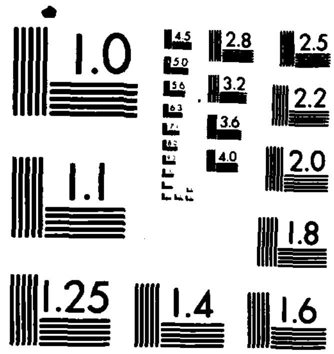
AD-A159 011 PRODUCIBILITY AS A DESIGN FACTOR IN NAVAL COMBATANTS (U) MASSACHUSETTS INST OF TECH CAMBRIDGE DEPT OF OCEAN ENGINEERING M L BOSWORTH JUN 85 N66314-70-A-0073

1/3

UNCLASSIFIED F/G 13/10 NL



DEPARTMENT OF OCEAN ENGINEERING

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

CAMBRIDGE, MASSACHUSETTS 02139

PRODUCIBILITY AS A DESIGN FACTOR IN NAVAL COMBATANTS

by

MICHAEL L. BOSWORTH

XIII-A

OE

SM(NAME)

JUNE, 1985

N66314-70-A-0073

PRODUCIBILITY AS A DESIGN FACTOR

IN NAVAL COMBATANTS

by

MICHAEL LANE BOSWORTH

B.S., United States Naval Academy
(1976)

Submitted to the Department of
Ocean Engineering
in Partial Fulfillment of the
Requirements of the Degrees of

OCEAN ENGINEER

and

MASTER OF SCIENCE IN NAVAL ARCHITECTURE AND MARINE ENGINEERING

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

June 1985

Signature of Author: Michael L. Bosworth
Department of Ocean Engineering, 15 May 1985

Certified by: Clark Graham
Clark Graham, Thesis Supervisor

Accepted by: A. Douglas Carmichael
Chairman, Ocean Engineering Departmental Committee

PRODUCIBILITY AS A DESIGN FACTOR
IN NAVAL COMBATANTS

by

MICHAEL LANE BOSWORTH

Submitted to the Department of Ocean Engineering
on May 16, 1985 in partial fulfillment of the
requirements, for the Degrees of Ocean Engineer and
Master of Science in Naval Architecture and
Marine Engineering

ABSTRACT

The objective of this study is to investigate a means of incorporating producibility as a major design factor in all phases of design of naval surface combatants. A categorization scheme is established for the consideration of producibility. A methodology is developed for evaluation of peacetime producibility concepts. A computer program enhancement to the ship synthesis model "ASSET" creates an interim producibility assessment tool by analyzing ship acquisition cost in further detail beyond the one-digit SWBS level. The proposed methodology and the producibility assessment tool are demonstrated on a proposed producibility concept.

Thesis Supervisor: Clark Graham
Title: Professor of Naval Construction and
Engineering

ACKNOWLEDGEMENTS

The author wishes to extend his most sincere thanks to Professor Clark Graham for his support, knowledge and encouragement during the preparation of this thesis. The deepest graditude is reserved for the author's wife, Barbara, whose love and understanding has been a constant blessing, and whose typing skills are a marvel.

TABLE OF CONTENTS

FIGURES

TABLES

CHAPTER ONE: SHIP DESIGN AND PRODUCIBILITY

1.1 NAVAL SHIP DESIGN

Naval combatant ships are among the most complex weapon systems in the world. To assist in putting a discussion of naval ship design in perspective, it is proper to examine the unique characteristics of the warship.

- Ships are the largest mobile objects in the world. The 'free' static buoyant lift of the displacement ship allows a relatively modest power to propel large payloads at relatively slow speeds.

- Naval combatant ships are required to perform numerous tasks. Most of these tasks necessitate a combination of subsystems. A single ship may consist of up to one hundred distinct subsystems.

- The personnel required to operate the ship and its integral systems must be berthed, fed, and supported aboard. (An extreme example is a modern aircraft carrier with air wing embarked. It has a crew of approximately five thousand men.)

- The system must operate in a hostile environment. The open ocean is a powerful and demanding element, made even more demanding when enemy forces are abroad seeking one's destruction, and normal weather avoidance is not possible.

- The combination of movement, the need for a high level of self-sufficiency, hostile environment, and the large number of subsystems creates a firm requirement for a high level of system integration.

The task of designing a naval combatant ship is difficult partially because of the ship's complexity. Several other elements add further to the difficulty.

- Due to the high level of ship complexity, the design process has many participants, each with his own diverse viewpoint. The drafter of requirements, the funding authority, the subsystem specialist, and the integrating designer need to achieve a high level of cooperation.

- The life of a ship can be quite long, often reaching half a century from conception to retirement of the last ship of a class. The design portion alone, including weapon systems, is usually on the order of a decade. Therefore the design must generally be flexible enough to accomodate future weapon modifications. Furthermore, various billets in the design process may be held by several individuals during the course of the design, in effect increasing the overall number of participants.

- Ships are high cost items, generally produced in very low numbers. This fact has resulted in a fairly conservative design procedure for ships that serves to minimize risk, discouraging innovation.

- The design is usually made in peacetime for a ship built primarily for service in war. The military requirements of war often conflict with peacetime demands of convenience and economy.

Due to the ship's complex nature, the design of a warship must necessarily be iterative in form. The 'best' or most suitable combination of design features cannot be determined directly by a rigid set of mathematical equations, but rather must include these equations based on physical principles with past empirical experience and future projections in a manner that is continually refined by iteration. This iterative nature of ship design is important to understand, and is best illustrated with the design spiral.[82]

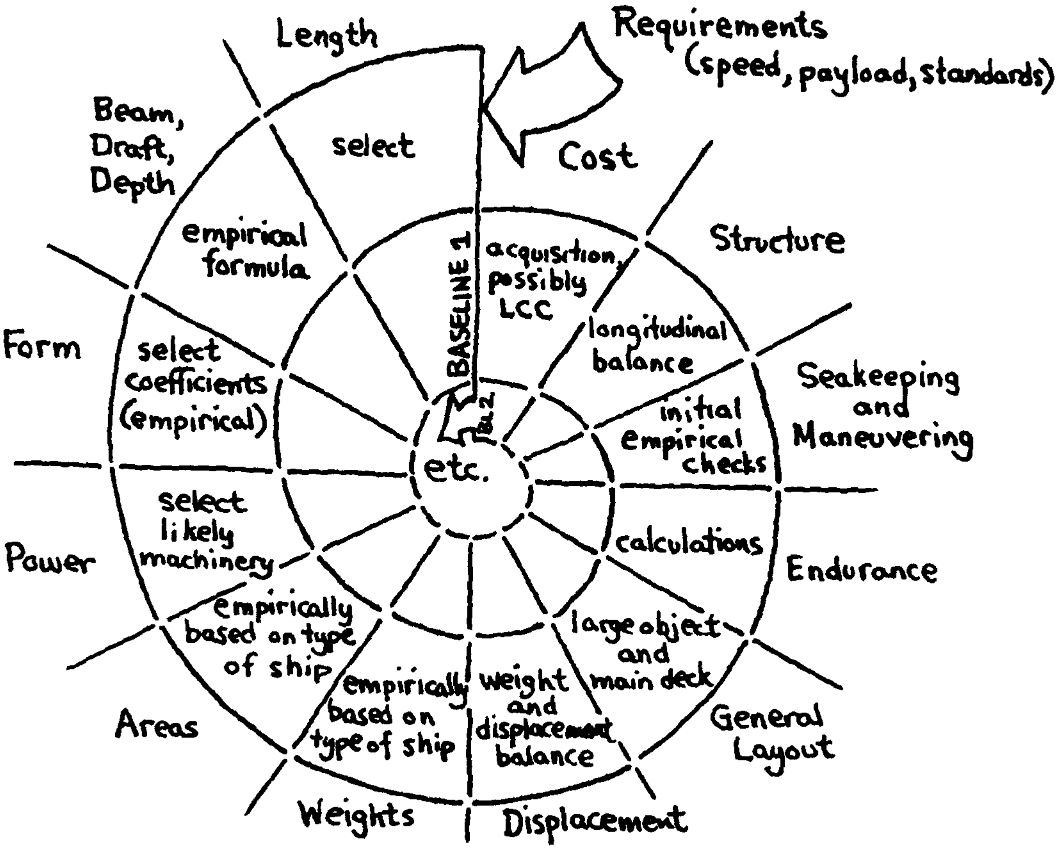


Figure 1: Design Spiral for Naval Architecture

The design spiral is a simplified graphical representation of how requirements begin the iteration and refinement of a ship design. Figure 1 is a possible design spiral for the naval architect. The naval architect is a subsystem specialist primarily concerned with hullform and hull structure. The integrating ship designer has a broader view, in which combat systems, propulsion plant, hull form, and hull structure all interact upon one another.

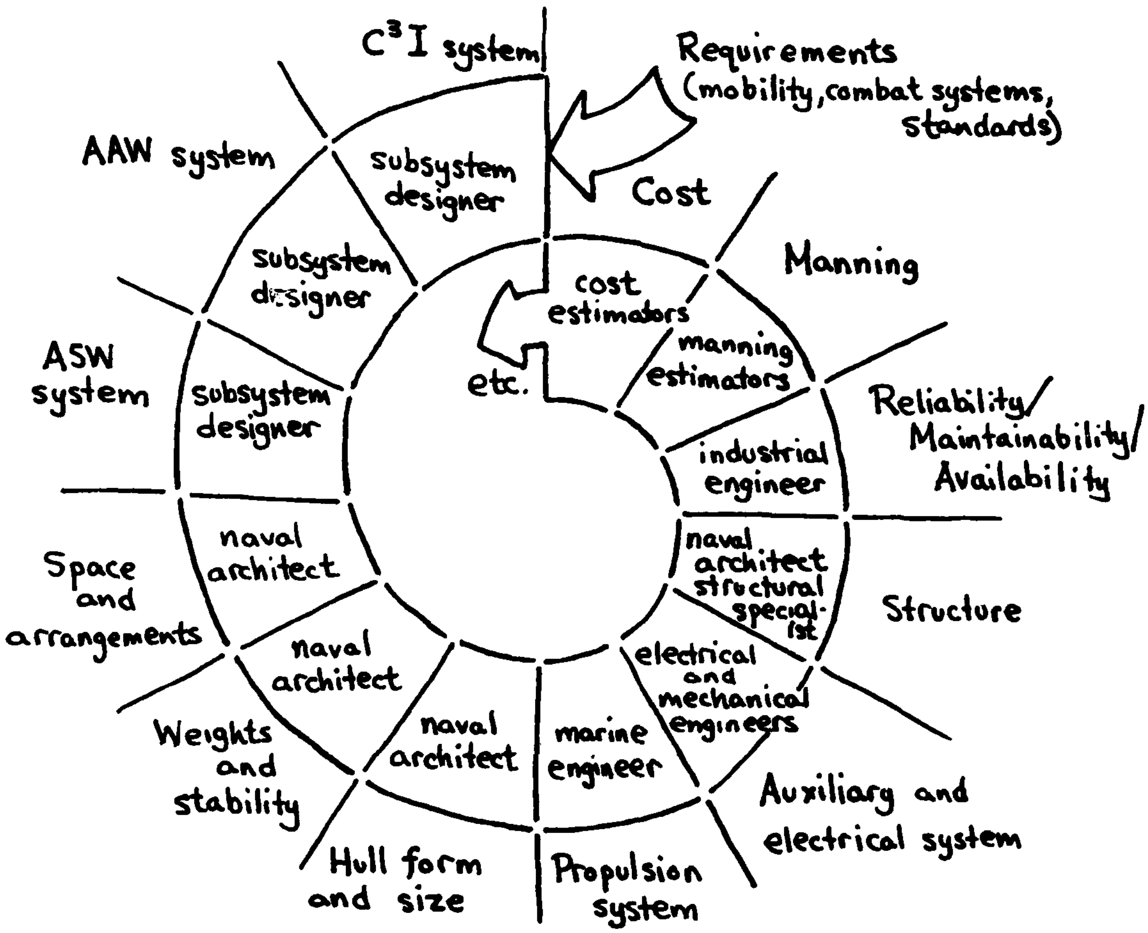


Figure 2: Design Spiral for Ship Design [39]

Figure 2 could become even more broad in the earliest phases of design, when requirements are still fluid and speed, payload, and other requirements can exist as spokes to a design spiral and thus be subject to iteration and revision. Each of the spokes of either design spiral could be further interpreted as having a mini-design spiral of its own.[39]

The design spiral emphasizes how the design homes in from the general to the specific solution, and illustrates the large number of major elements which affect the chosen solution. A modified model of the design process which better illustrates the temporal aspects of ship design is that where the spiral becomes a helix superimposed on a gradually converging conical solid.

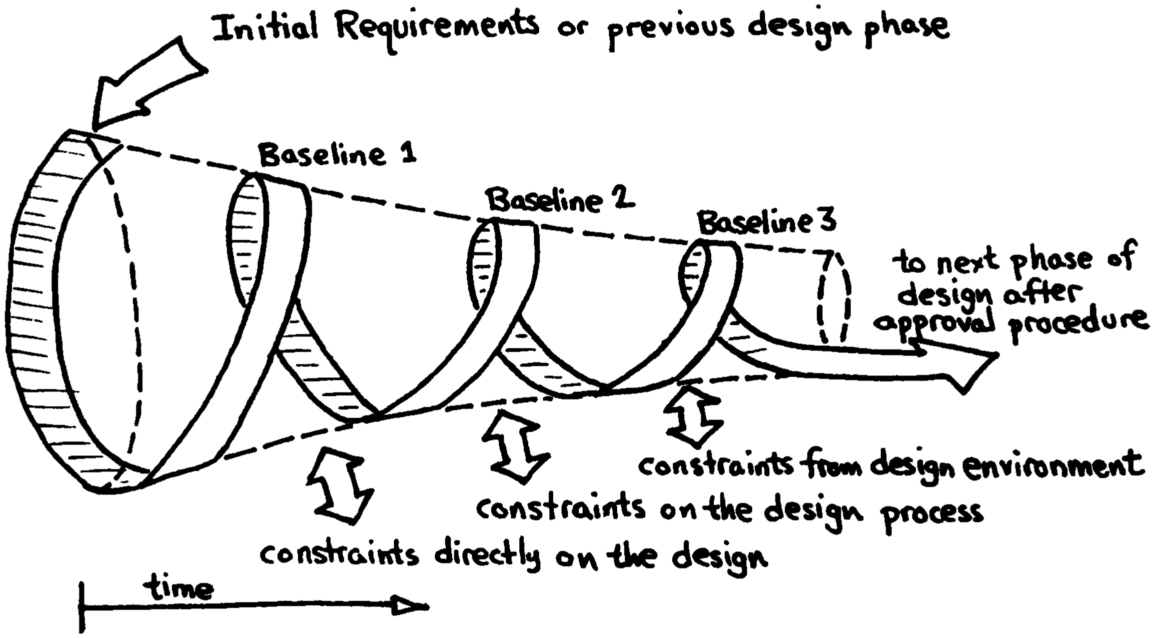


Figure 3: Helix Model of Ship Design Process

This model has the advantage of illustrating that the many requirements and constraints on the design are fundamental to the process. These constraints serve to refine the design a time and effort progresses. Viewed from the left end, it is the design spiral.

1.2 DESIGN FOR PRODUCTION

Producibility is not presently considered a major element in the ship design process ('a major spoke of the design spiral') for several reasons.

- There exist a myriad of other elements that are considered more critical.

- There has been a decided lack of visibility and external pressure to increase the producibility of the ship design. Producibility is not as patently obvious as a hydrostatic problem which results in severe list, or a naval gun that cannot fire. Lack of producibility in design is more insidious but no less important.

- There is a perception that the design community *does* address producibility through weight minimization or cost constraints. While these spokes *are* related to producibility, they can easily create a design decision that is out of equilibrium. (Note 1)

Note 1: The equivalence of ship weight to ship acquisition cost is a common falicy. While it has some merit in conceptual studies, it has persisted far past its range of reasonableness due to its inherent simplicity and its ability to be easily measured. However, weight as a measure of cost must be viewed with extreme suspicion in an era of technical

- A lack of awareness of the relative leverage of various ship subelements and design phases for improving producibility and thus increasing the ship's overall cost-effectiveness.

- A lack of detailed data on specific producibility concepts.

- A lack of any rigorous methodology for the assessment of producibility.

Producibility is worthy of being analyzed as a major spoke of the design spiral in the earliest design stages, as well as throughout the entire conceptualization, design, and production cycle. The concept of 'design for performance' has

innovation. An extreme example of the "weight as cost" concept running afoul is the Patrol Hydrofoil Missile (PHM). The PHM-1 leadship used small, lightweight structural sections, close stiffener spacing, and thin gage welded aluminum materials to save weight in the weight-critical high performance ship. While the result was low weight, excessive costs resulted from problems such as weld distortion, part fitup, and poor welding accessibility. An extensive structural redesign for the follow ships resulted in a mere 5% increase in weight for a 68% reduction in typical midship bulkhead cost. [12]

been stressed up to now. 'Design for production' should be considered equally important.[14]

In the past decade and a half there has been considerable effort to reduce the cost of warships. The "Design-to-Cost" design philosophy that produced the U.S. Navy's Oliver Hazard Perry (FFG-7) class guided missile frigate is indicative of current efforts. Graham and Nickelsburg mention three ways to reduce cost; (a) reduce performance, (b) take advantage of technology, and (c) improve management to produce a tight design. They conclude that, ". . .the dominant method for reducing ship size and cost involves the reduction in ship performance." [37] 'Design for performance' and 'design for production' should be considered as two equally important aspects of overall design, as the naval fleet should itself be considered as a system. That is, the ship designs developed and produced should enhance the fleet's probability to achieve victory in a fleet to fleet conflict, rather than narrowly focusing on ship to ship contests. The numbers of ships (or weapons) will be crucial in the fleet-to-fleet (or even more broadly nation to nation) conflict. The numbers and types of ships will be defined by cost, production capacity, and schedule, in interaction with the ability and will of the nation to purchase and support these ships or other weapons systems.

1.3 PRODUCIBILITY CONCEPTUAL FRAMEWORK

There are two major classifications which are useful for focusing attention on the subject of ship producibility: "wartime producibility" and "peacetime producibility". The former is primarily concerned with schedule and production rate; the latter is primarily concerned with cost considerations, (primarily ship acquisition cost but also overall life cycle costs). The two classifications will have many producibility concepts in common, but the methods of evaluating those concepts will be quite different. The chapter that follows briefly examines the wartime producibility issue while the remainder of the thesis deals with peacetime producibility.

1.4 THESIS OBJECTIVES

This thesis is intended to provide a groundwork for consideration of producibility as a design factor in naval combatants. The specific objectives of the thesis are:

(a) to examine the producibility conceptual framework proposed in section 3 above. (chapters 2 and 3)

(b) to explore the peacetime (cost) aspects of producibility and determine how it should be considered as an element of ship design. (chapters 3,4, and 5)

(c) to examine some existing design synthesis tools, and evaluate their suitability for expansion into a producibility assessment model. (chapter 4)

(d) to create a preliminary peacetime producibility concept database. (Bibliography and Appendix A)

(e) to determine a methodology for examination of producibility concepts in design, during the early phases of the ship design process which ship characteristics are still fluid and later stages when characteristics are fixes. (chapter 4)

(f) to exercise the methodology on several producibility proposals from the database. (chapter 5)

(g) to discuss the implementation of this methodology in the United States Navy. (chapter 6)

A most important portion of this thesis is its recommendations for future study, which appears in the final chapter.

CHAPTER TWO: WARTIME PRODUCIBILITY

2.1 THE FACTORS OF TIME AND VOLUME OF PRODUCTION

In wartime, or in a pre-war mobilization environment, schedule is of the essence, and the task of constructing a large number of ships in time to affect the outcome of the conflict takes overwhelming precedence. Considerable historical data concerning wartime producibility exists, and this type of data dominates post World War Two producibility research material.

2.2 BRIEF HISTORY OF WARTIME PRODUCIBILITY

An early example of large scale warship production is provided by the Arsenal of Venice in the 16th century. At that time, the Venetian State and Navy were at their zenith of power, and the primary threat to Venetian maritime interests was from the Ottoman Empire. The Arsenal became perhaps the largest industrial plant in the world, covering sixty acres of ground and water and employing up to 2000 workers. This industrial complex had a three-fold purpose: (a) the manufacture of ships, arms, and equipment; (b) the storage of the equipment until needed; and (c) the assembly and refitting of the ships on reserve.[79] In 1570, in mobilizing for the campaign of Lepanto, the Arsenal mobilized forty two empty hulls lying in reserve for her own fleet, twelve hulls for a Papal squadron, and laid down sixty-six new keels. In less than half a year, Venice quadrupled the size of her active fleet. [84]. To accomplish this feat, the Arsenal utilized several practices ahead of its time: the numbering and warehousing of finished parts, assembly-line outfitting of the ships, standardization of parts, and inventory control.

In the present century, there have been two major naval wartime mobilization efforts in the United States: World War One and World War Two.

Producibility in World War One

World War One was a one-ocean war for the United States navy, and the U.S. entered the conflict quite late. Imperial Germany invaded Belgium in August 1914 to commence general European hostilities. Beginning in February 1915, Germany commenced a submarine blockade of the British Isles, and the submarine became the greatest maritime threat to the Allied cause. In 1917, Germany intensified the blockade with "unrestricted submarine warfare", in which all shipping, enemy and neutral, which entered the war zone was liable to destruction. The declaration of unrestricted submarine quickly brought the United States formally into the war on the side of the Allies, in April 1917.

The convoy system was the primary defense for slow-moving merchant ships against the submarine. Destroyers were pressed from general fleet service to become the most capable convoy escort, but there were never enough destroyers. Therefore some new, smaller classes of ASW escorts were devised to provide ASW protection for coastal shipping, more quickly, or at a lower cost.

The Sub-chaser type of patrol craft was initially authorized in a March 1917 act, and eventually nearly 450 of these were authorized. Much less a ship than the 300 foot, thousand ton destroyers of the era, they were 110 feet long, displaced a mere 85 tons, and had a speed of 18 knots. At 10 knots, they had an endurance of 900 nautical miles. Their primary virtue was that, being of wooden construction and small, they could be constructed by very small yards and help in coastal escorting.

A more destroyer-like ship was the Eagle class patrol escort (PE). In June 1917, President Wilson asked Henry Ford of automotive fame to be on the U.S. Shipping Board. The Board was to be responsible for construction of merchant ships to replace losses to submarines, and for construction of some emergency warship types. Mr. Ford stressed the need for series production, and wished to bring the techniques of the automotive assembly line to the shipbuilding industry. The Eagle class PE was an austere design that had a 200 foot length overall, displaced 615 long tons, and had a sustained speed of just over 18 knots on its single shaft. It was armed with two 4 inch guns and a 3 inch gun, and was intended for ocean escort. Its lines were designed for construction with flat plate, and it was built on a 1700 foot assembly line in Detroit on the Rouge River. Originally, one hundred were authorized, but this number was reduced to sixty as the war neared its end in November 1918. Only seven were completed in 1918, in time for the war; the remaining 53 were completed the following year. Some saw service in the U.S. Coast Guard in the 1920's, and most were decommissioned in the 1930's.[70] The strength of the PE program was that it did use alternate building facilities and therefore did not compete with the main destroyer building program. It must be recognized as a failure, though, as the program did not substantially aid the war effort and the ships did not survive long in peacetime service, although about twenty served in World War Two as coastal escorts. [71] The inexperience of the automotive personnel in shipbuilding was a major factor in the early shipbuilding schedule not meeting Ford's projections.

The dilemma that was common to the First and Second World War was: should the sophisticated prewar designs continue to be built, or should an austere, specialized, mass-production design be pursued? [28] In 1917, the existing design was kept in production, although the need for intense production was dictated by the anti-submarine convoy escort demands. The existing design was clearly a fleet destroyer, intended primarily for surface torpedo attacks against enemy capital ships, defense of the fleet against enemy torpedo attacks, and for advance scouting. This was the correct decision in a war of short duration, for even by continuing with an existing design, the destroyers were hard-pressed to be completed before the end of the war in any numbers.

The World War One mass-production destroyer was a modified version of the Caldwell class of 1916.

Table 1:

Flush Decker Mass-Production Destroyer Characteristics [28]
USS Gwin (DD71)

LBP = 310'0"	4 4"/50 guns
Beam = 30'7"	12 (4X3) 21 inch torpedo tubes
Depth = 19' 8 1/2"	2 anti aircraft guns
	1 Y-gun (depth charge projector)
C_B=0.51 C_X=0.86	2 depth charge racks
	(no sonar originally installed)
SHP (trial) = 19,930	
Speed (trial)= 30.3 knots	
Δ_{FL} = 1,192 LT	Endurance = 2,500 nm at 20 knots
	= 3,400 nm at 15 knots
W_{fuel} = 205 LT	

By May 1917, contracts for a total of 61 destroyers had been let (through hull DD 135). This number of hulls strained to capacity the then six private destroyer building yards and Mare Island Naval Shipyard. Existing contracts at these yards for six battleships, one battle cruiser, and seven scout cruisers were suspended to free capacity for the needed destroyers. Only two months later, fifty more destroyers were ordered, to hull DD 185, to the same design. [28]

It is interesting to note that the above 111 destroyers were of the same preliminary design, but that there were two basic detail designs. One detail design was by Bath Iron Works, used by the Navy Yards and most private yards, and the other was by Bethlehem Steel for its own yards. Performance of the ships varied, even when constructed to the same design: the first Bath unit, Wickes, was good for 3400 nm at 20 knots, but the Mare Island destroyers were good for little more than half the range of the Bath destroyers. The building times varied considerably, from USS Ward at Mare Island in only 70 days, to a more typical wartime building time of eight to ten months, to the solitary destroyer built by Charleston Naval Shipyard (Tillman) which took 21 months to complete.

Eventually a total of 273 destroyers were ordererd in the wartime program, 35 of which were built at a new Naval Destroyer Plant at Squantum, Massachusetts that had ten slips. Only six of the 273 were cancelled, but only 39 of the 267 built were commissioned by the end of World War One. Of these, approximately a hundred were decommissioned or lost to peacetime accidents between the World Wars, the bulk being sixty decommissioned Bethlehem built ships with Yarrow boilers that would have required early reboilering. The rest went on to serve in some fashion in World War Two; some fifty were transferred to the Royal Navy, others ended up in the Soviet or Norwegian Navies; the bulk remained in U.S. service as destroyers, fast transports, or minelayers. Some thirty-five were lost during World War Two, the rest were discarded after the war. The last of this class in service was DD 168, which was retired from the Soviet Navy in September 1952, thirty-three years after first commissioning. [28]

In World War One, continuation of the existing pre-war destroyer was the option selected, but studies for special anti-submarine warfare (ASW) destroyers were conducted. The major issues concerned trading away top speed for increased endurance, and for reduced size and cost. Some of the trade-offs considered were:

(a) reduce the four torpedo banks to two banks.

(b) reduce the four boilers to two boilers, reducing length from 310' to 280', and thus displacement.

(c) reduce existing high performance destroyer weight-saving techniques to ease mass-production, for a weight addition of approximately 130 LT.

(d) have a full 310 foot destroyer hull but with half the power

(e) develop a new direct-drive turbine to eliminate the reduction-gear bottleneck.

On 7 August 1917, sketch designs for various austere destroyers were submitted, and three days after the Secretary of the Navy approved one that involved a full 310' hull with half-power and direct-drive turbines. The major builders soon reported that detail plans would entail considerable time delay, so the program was altered to a slight variant of the mass-production fleet destroyer discussed previously, hull DD 186 on. [28] In World War Two service, many of the flush-deckers had one of four boilers removed and replaced by fuel tankage to increase endurance for convoy duty.

Producibility in World War Two

In World War Two, the war was to be longer for the United States, and it was to be a two-ocean war. Along with a submarine war in the Atlantic requiring escorts and merchant ships in quantity, there was a full scale fleet to fleet conflict in the Pacific and a need to provide craft for a landing of troops on a hostile shore. Different from World War One, the U.S. Navy decided early to pursue a program of both fleet destroyers and a new austere destroyer that became the "destroyer escort" (DE). There was considerably more pre-war preparation in World War Two, much of it based upon World War One experience. The Maritime Commission of World War Two was equivalent to the Shipping Board of World War One, and was tasked with building not only merchant ships, but also naval transports, naval auxiliaries, and even numerous warships; landing ship tanks (LST), escort aircraft carriers (CVE), and destroyer escorts (DE). The Navy had its own program for procuring the majority of its warships; the direct cost of ships delivered during World War Two was about $18 billion (FY43) for the Navy (exclusive of ordnance) and about $13 billion (FY43) for the Maritime Commission. The Navy dominated contracts in the traditional shipbuilding areas, particularly in the yards of the Northeast coast, whereas the Commission was forced to develop shipbuilding capability where there had been little, on the West coast and the South Atlantic states. [59]

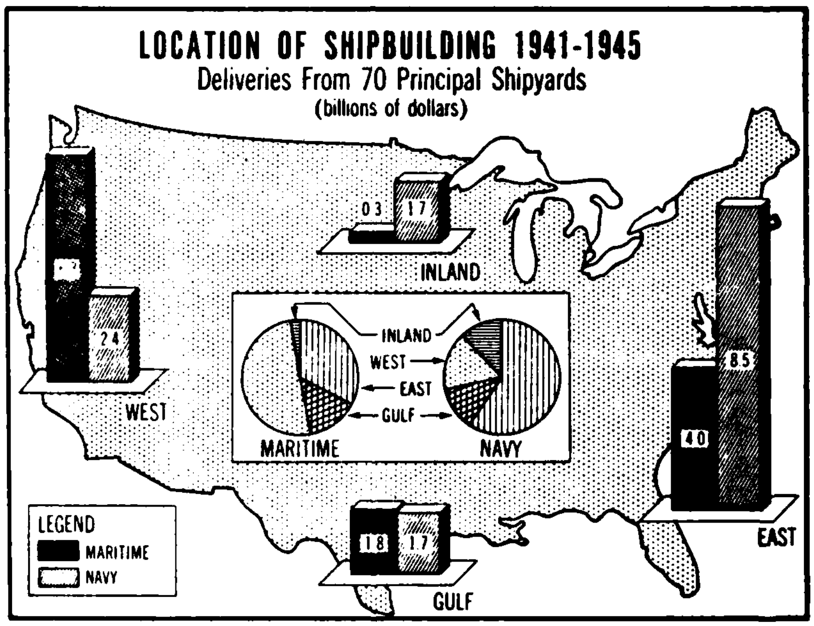


Figure 4: Location of Shipbuilding, 1941-1945 [59]

Although this thesis is predominately concerned with combatant ships, the emergency-type merchant ship that composed the <u>Liberty</u> program is illustrative. The basic decisions concerning the <u>Liberty</u> ship were made in the year before

Pearl Harbor. The _Liberty_ was based upon the British _Ocean_ class design, with a length of 440 feet, a speed of 11 knots, and a weight carrying capacity of about 10,000 tons. In January 1941, when the key points of the _Liberty_ were being decided, a straight-lined form based on a T-2 type tanker for production ease was considered. Although its tow-tank tests had proven favorable, no such vessel had even been built.[59] Such straight-lined hull form concepts had been under discussion since 1917.[65] It was considered too risky to adopt a hull form with untried seakeeping qualities, so the British _Ocean_ hull form was utilized. A single midship deckhouse was used instead of the British two-house design, both for greater crew comfort and to reduce piping and heating requirements. Water tube boilers were used, and fuel oil vice coal. The contra-rudder developed by the Goldschmidt Corporation of New York was used in the American design for a small increase in speed and maneuverability and a 40 percent reduction in rudder cost.

Although the British plans existed, a tremendous amount of detail design had to be redone because of the changes and because of differences in U.K. and U.S. design practices and standards. Gibbs and Cox of New York was the design agent. Extensive use of welding, then quite new, was planned, and wartime steel shortages dictated some further changes: reduced anchor chain, narrower plates, and fewer number of gauges for steel plate.

The first Liberty Ship was delivered in September 1941, the Patrick Henry. The average time from keel laying to delivery for Liberty ships was 240 days in January 1942, 150 days in May 1941, and steady at about 50 days from November 1941 through 1945. Each yard building Liberty ships had a long delivery time on its first few ships (200 to 300 days) that rapidly dropped to less than 100 days after the yards had been delivering for about three months.[59]

The Navy had subchasers (SC) built on the model of the World War One subchasers; they were wooden and of length 100 feet, with twin screws powered by pancake diesels for speeds of 15 knots for one version and 21 knots for another version. [70] It took from five to eight weeks for one of these dimunitive vessels to be built, and they were manned largely with reservists trained at the Submarine Chaser Training Center that was commissioned at Miami in March 1942. That school eventually trained personnel for crews of 285 DE's, 256 PC's, 397 SC's, and 150 other craft.[71]

The hope for an early landing across the English Channel never bore fruit, but numerous beaching and landing craft were built for it and used in the later Mediterreanean and Normandy landings. Some of these craft were built with the excess Maritime Commission capability from its successful series production of merchants. Some came from delaying the production of destroyer escorts.[71]

The Landing Ship Tank (LST) was designed in November

1941 to British requirements to carry the newest, largest tanks across the ocean and deposit them on a beach. The Bureau of Ships made the concept design, which was for a 280 foot, 1400 ton vessel that could beach 500 tons. By January 1942, the Bureau had finished a preliminary design, then the contract and detailed plans were made simultaneously by Gibbs and Cox to speed the process. By October 1942 the first LST was completed. As completed, the LST was 328 feet long overall and displaced 4100 tons full load. It was capable of carrying a military load of 700 tons and dispatching it to a 1:50 slope beach through hinged bow doors.[74] Its speed was rather slow, 11 knots, with twin screws powered by diesel engines. An LST's deadweight tonnage, 2,300 tons, was only one-fifth of the 10,600 deadweight tons of the Liberty ship, but it construction was more complicated and required more manhours per ship than a Liberty.[59]

A larger and more complex emergency ship program was the escort aircraft carrier. Some escort carriers, the earliest in March to June 1941, were converted from merchant ships. The Maritime Commission contracted for fifty escort carriers (from Kaiser Corporation) to standard commercial practice for hull and machinery, and Navy specifications developed for the previous conversions in other appropriate areas. The length (waterline) was 490 feet, with a light displacement of 6,890 LT. The propulsion power was from reciprocating steam engines, to avoid acquisition conflict for turbines, gears, and diesels required for other designs in production. It had twin shafts, vice the single screw of the conversion, and had separate machinery spaces.[59] The CVE was capable of operating over twenty aircraft. The most successful use of the CVE's was as the center of a hunter-killer group, in which an escort carrier and perhaps three destroyer escorts roamed freely in search of enemy submarines. The first converted CVE, USS Bogue, got into action escorting convoys in March 1943. Bogue also conducted the first CVE hunter-killer operations in June 1943.[71] The first Kaiser escort carrier was delivered on 8 July 1943, and the fifty ship contract was completed 8 July 1944. "In view of the size and the amount of complex equipment involved in a (CVE), it was a notable achievement in multiple production."[59] In all, over 120 CVE's were built of three classes, the later Commencement Bay being considerably larger, of 9,500 tons light displacement. [27]

The decision in World War Two was to continue production of the prewar, sophisticated destroyer classes (now typically 350 feet long with a 2,000 ton displacement), but also to develop an austere class like the British corvette, the Destroyer Escort (DE). The first Benson/Livermore class fleet destroyer was commissioned in June 1940. Twenty-eight of the ninety-six ships of the class were commissioned before Pearl Harbor, and Benson keels were laid for a year after the war started for the United States. Some modifications were made to the design to ease production: the radius in the deck edge forward was eliminated, Bofors automatic anti-aircraft guns were replaced by Oerlikons due to shortages of the former, curves were eliminated in the superstructure, and directors were lowered to the pilot house roof. Other-changes in armament came about from the need to improve ASW and AAW performance.[28] The other class produced in great numbers was the Fletcher (DD 445), of which 175 were built. The Fletcher was considerably larger than previous fleet destroyers, (with a length of 369 feet and a full load displacement of 2,800 LT), being the first design truly free of treaty limitations. The evolution of the design began in Fall 1939 with conceptual studies, and the detail design was carried out by Gibbs and Cox in 1940. Eighteen Fletchers commenced building before Pearl Harbor and the first Fletcher was commissioned in June 1942. New yards were built, or repair yards upgraded to naval construction; existing yards were extensively expanded. The Fletcher design had relatively small acquiescence to production requirements, with the major modifications being for increased combat effectiveness in their fleet defense role. In mid 1942, the design of the next mass-production fleet destroyer was evolving, the design that was to be the Sumner class. The changes of the Sumner over the Fletcher were for combat effectiveness and survivability: twin mounts, duplicate emergency generators, duplicate evaporators, a Combat Information Center (CIC), and an increase in both main and secondary batteries. However, the changes were made with only a nominal increase in displacement and none in length, in order to require no enlargement of existing building facilities, and the main machinery was the same as for the Fletcher, and already in production. The switch from production of the Fletchers to production of the Sumners was performed gradually to avoid disruption, and the first Sumner was commissioned in December 1943.

Table 2: World War Two Mass-Production Fleet Destroyer Characteristics [28]

design characteristics [dim]	Benson class	Fletcher class	Sumner class
length (LBP) [feet]	341	369	369
beam (B) [feet]	36	40	41
depth (D) [feet]	20	23	23
displacement (Δ_{fl}) [LT]	2030	2700	2890
fuel weight (W_{fuel}) [LT]	500	491	538
endurance [nm/knots]	6500/12	6500/15	6500/15
5-inch guns	5 (5x1)	5 (5x1)	6 (3x2)
torpedo tubes	5 (1x5)	10 (2x5)	10 (2x5)
speed (V_s) [knots]	35	37.8	36.5
SHP [horsepower]	50,000	60,000	60,000

World War Two Destroyer Escort

The interest in an austere escort such as the World War

One Eagle Boat was not revived until 1937, when the 173 foot patrol craft (PC) began its evolution. The vast numbers of World War One four-pipers were considered sufficient for long range ASW work. A 1939 suggestion was made for something larger than a PC and smaller than the current destroyer, to be delivered in large numbers more quickly. The War Plans Division, which proved later to have predicted World War Two requirements as closely as anyone, suggested a simple, robust vessel, concentrating in ASW and AAW, good for 25 knots, and displacing around 1200 tons. Diesels were suggested as a possibility for mass production and for endurance. Torpedoes were excluded. [28] Nothing came of this proposal until November 1940, when some Presidential intervention revived interest in austere destroyers. The CNO asked Preliminary Design for a ship of 750 to 900 tons, with 3 or 4 5" guns, capable of 25 to 30 knots, suitable for convoy escort. That high a payload driven at such a high speed proved infeasible. By 1941 the DE had evolved to 2 5" guns and 24 knots, and by April of that year the General Board had decided that the DE had too little capability for a ship so close to the size of a 1930's destroyer. Captain Cochrane, head of Preliminary Design, continued to develop the design despite the disinterest of the General board. He stated, ". . .the Bureau believes that (the DE's) value would increase almost in direct ratio to the rapidity of their construction. Every effort would be made during the development of the design to obtain simplicity in both hull and machinery. . ." A study suggested the following comparative costs. . .

destroyer	100%
destroyer escort	55%
173' PC	20%

In August 1941 production was approved for fifty British DE's, modified by substitution of 3 3" guns for the 2 5" originals. Norman Friedman states that, "the Navy was able to receive both its general-purpose destroyers and its specialized escorts. . .the DE program competed with destroyers, if at all, only in the issue of the supply of 5-inch guns. . The scramble for power plants shaped the DE program." [28] To avoid the bottleneck for geared turbines such as those used in major combatants and fleet destroyers, diesels, turbo electric drive, and geared turbine alternatives were developed. The gun battery was also determined by availability: either 5-inch or 3-inch main battery, and a secondary battery of the less effective but more producible Oerlikon 20 mm. The DE was a single mission ship, designed for ASW, but capable of some AAW and anti-surface self-defense. Once the threat had solidified, a minimum ship to meet the threat could be devised.

The first DE keel was not laid until February 1942, and production geared up slowly. The program suffered from shifts in priority to landing craft, and by the time the DE program was geared up (late 1943) the Atlantic ASW emergency was being reduced. A large fraction of the DE's were constructed in inland yards; some were constructed by the Maritime Commission to a modified British corvette design (the "PF"). Over a thousand DE's were ordered, but by late 1943, cancellations were made in great numbers to clear the ways for an augmented landing craft program. Only 563 were completed, 96 of these being the Maritime Commission's production simplified PF. [28]

For mass-production, several new yards were constructed. Work done inland involved certain adjustments; the smaller Greak Lakes yards had cranes that could typically handle only 10 tons, whereas other coastal yards might be capable of handling a forty or fifty ton prefabricated section. Also, to get the PF's from inland to the ocean, pontoons were attached to reduce the frigate's draft and the masts had to be taken down to fit under bridges. [59]

The specific lessons learned from the DE were brought forward in a 1945 board. The board concluded:

(a) the DE's, particularly the diesel types, are too slow to combat the newest German submarines

(b) the 5-inch guns are preferred over the 3-inch, in a powered mount,

(c) the open-bridge is preferable to the closed-bridge (AAW),

(d) that gas turbine main propulsion should be considered.

British comments were strong about the excessive rolling of the design. The trouble was not excessive angle of roll, but rather rapid recovery from large roll angles. The Wartime DE's were not particularly attractive to the post-war U.S. Navy, but they proved useful in small foreign navies for many years. [28]

The Postwar Destroyer Escort

In the early 1950's design studies for a new mobilization prototype were undertaken. Low cost and small crew were to be emphasized, a primary consideration for the ship being its suitability for mass-production. The design grew from an updated PC to a destroyer escort, and thirteen Dealy class were built beginning 1954. An attempt to create an even less expensive ship resulted in DE 1033 (Claud Jones) and its three sisterships. Neither class was popular in the fleet due to light armament and slower speed than destroyers, and other quarters suggested that a far more austere escort could and should be built.[28] Follow-on classes (Bronstein, Garcia, Knox, Brooke, and Perry) have evolved into something more than the traditional escort, and something less than a full-fledged destroyer. They are the result of strategic thinking of the late fifties and early sixties than envisioned the war being fought with only existing forces and weapons. They are not mobilization designs.

2.3 RECOMMENDATIONS CONCERNING WARTIME PRODUCIBILITY

The primary lessons from history for wartime producibility are;

(a) There must be a *recognized national need and a measurable goal*. The early Liberty ship program certainly had both of these, and it contributed to production being able to exceed projections considerably.

(b) *Series Production* must be maximized, and design changes minimized or phased in gently. Much of the success of the Liberty program (compared to the mediocre showing of the DE program) involved the DE's design changes and program shifts.

(c) The *timing* must be accurate. Ships must be ordered months or years before they are delivered, and the changing tide of war makes production need forecasts difficult. The DE program was slowed tremendously by interference by the landing craft program, for a landing that eventually occurred two years later.

(d) *Design simplification and flexibility*. Alternate power plants made possible DE deliveries that would otherwise have been impossible. The Maritime Commission's simplified CVE and PF designs could be more easily constructed in alternate yards in a rapid manner.

(e) *Production facilities*. The key to high emergency production is to quickly develop alternate yards and expand existing capabilities.

The United States Navy cannot predict the form of its next war, but America's dependence on the sea certainly suggests the possibility of a lengthy maritime conflict. Wars tend to prove longer than pre-war predictions. Recent literature is contradictory. One author notes the Soviet study of the German submarine campaign in World War Two, but states that the Sovies maritime strategy will be defensive and geographically limited in theme. However, he acknowledges that "the large number of platforms available to the Soviets will allow at least a fraction to be deployed on a worldwide basis. . . against naval and commercial vessels. . ." Another current writer suggests that the Soviets could apply the 'fleet in being' concept with their surface forces, while they take aggressive maritime action against seatrade, through mining and submarine action.

Recommendations for the United States Navy in the last decades of the twentieth century must acknowledge that the U.S. Navy is <u>the</u> power projection navy of the free world. Also, the realities of military funding in peacetime must be taken into account. A modern, front line naval combatant takes ten or more years to design and construct, but for many tasks, only a highly sophisticated ship will do. The U.S. Navy has chosen to construct only the larger, more sophisticated combatants. The least of the modern U.S. ships are the <u>Oliver Hazard Perry</u> (FFG-7) guided missile frigates, a 4000 ton, 30 knot ship with two helos and both ASW and AAW roles.

The choice to build larger, more capable ships is wise, and has its parallels in both pre-World War eras. However, through preparation, the lead time to produce austere ships in time of crisis can be substantially reduced. The recommended actions include:

(a) evolution of the sophisticated designs. This retains design expertise in a team framework in all ship classes and limits problems of block obsolescence. When the time comes to accelerate sophisticated ship production, the available design is as developed as possible.

(b) streamlining of decision making. The 'committee' approach to decision is notoriously slow, but would be even more hazardous in a pre-war environment. At that time, the crucial decision will need to be made of whether to produce only the sophisticated pre-war design or to also produce the austere designs. This production decision will depend upon the expected length of conflict, whether the existing production base will be saturated, and whether the austere designs will be effective in the anticipated engagement.

(c) predesign to the detailed plan level of certain austere wartime designs. These designs would be maintained current ('evolved' as are the sophisticated designs) and would encompass the following features;

i) smaller/simpler for production at alternate shipbuilding sites (not otherwise usable for major naval combatant construction)

ii) use of alternate subsystems (not necessarily optimum from an effectiveness standpoint) such as propulsion plant or armament, that do not compete with the limited supplies available for the existing pre-war sophisticated designs.

iii) simple to operate for manning by hurriedly trained reservists.

iv) flexibility of design to accomodate alternate subsystems as available or as desirable for various wartime missions.

v) utilizing lesser standards for habitablility, environmental control, future growth and other items to simplify and speed construction.

vi) consideration for post-war roles or conversions on a not-to-complicate basis.

(d) the detailed plans thus generated would be validated by actual construction of a limited number of prototypes. This would also provide an opportunity to train mobilization production personnel.

(e) the identification of potential production bottlenecks to allow development of mobilization production capabilities. For example, if large scale gears were a primary bottleneck, incentives through legislation could be provided for private development of such a capability, or machinery to that purpose could be stockpiled.

(f) development of computer-aided design (CAD), computer-aided graphics (CAG), and computer-aided manufacturing (CAM) to facilitate the design and/or modification procedure.

(g) development of a design tool for wartime producibility concept and feasibility design: a design/schedule synthesis model which integrates component lead times, supply, production site capability, and cost-benefit to permit examination of a wide variety of designs in early phases of design.

The key recommendations are items (c) and (d): the detailed plans in hand prior to the crisis and validated in-so-far as budget permits by prototypes construction. The list of crucial designs to be assembled should include;

- * Escort Frigate (ASW)
- Escort Frigate (AAW)
- * Escort Carrier
- * Multi-purpose Cargo (general cargo, roll-on/roll-off, container)
- Oil Tanker
- Landing Craft
- * Mine Warfare Craft
- Fast Patrol Boats (missile)
- Diesel attack submarine

* = higher priority

The Maritime Administration, in the late seventies, performed a feasibility design for a multi-purpose cargo ship. [122] For a start, based upon the best current estimates of war plans, this cargo ship design should be further developed, as should an austere ASW frigate and mine clearance craft. The escort carrier design will be largely controlled by the aircraft procurement plans; either through continuation of prewar aircraft designs, an austere design, reactivation of mothballed aircraft, or commercial aircraft conversions.

CHAPTER THREE: PEACETIME PRODUCIBILITY

3.1 THE FACTOR OF COST OF PRODUCTION

In peacetime, the acquisition cost of the system is of primary importance. Operating and support costs are also of importance, but the government funding process emphasizes acquisition cost, taking a shorter term view than is perhaps wise. The lower the acquisition cost, then, the more navy that can be purchased. President Thomas Jefferson, desirous of a low cost navy, invested in small gunboats rather than the frigates and ships of the line of 1800. This case points out another maxim: one must get effectiveness as well as low cost, or the cost is too high. Jefferson was soon forced back to a more traditional ship type composition, to combat the Barbary pirates. The solution must be, in single hyphenation, "cost-effective". As mentioned in chapter 2, it is in the peacetime navy's interest to construct mostly large, sophisticated ships, for these large ships require more building time than most wars would provide, require a sophisticated shipbuilding base that must be consistently supported, and require a higher level of training which can be provided in peacetime.

3.2 CATEGORIES OF PEACETIME PRODUCIBILITY

In deciding how to approach the challenge of reducing the acquisition cost of naval ships, one can consider five broad categories of peacetime producibility. They are: Fleet Concept, Preliminary Ship Layout, Production Details, Shipyard as Factory, and Economic Considerations.

3.2.1 Fleet Concept

Every country, be it large or small, has its own strategic problems. Each country must decide upon the armed forces and weapon systems required to protect its interests. A naval power such as the United States plans a long term program for the composition of its navy and for that navy's building policy over several years.

Within the United States, Congress, the Secretary of the Navy, the Chief of Naval Operations and the Systems Commands all participate in a process to define the requirements for new ships. These requirements for their capabilities are based upon their intended mission, and will generally include statements concerning their combat systems, mobility (speed, range, and seakeeping ability) and survivability. On the other side of the spectrum are constraints. Due to the political and financial realities of the country, cost, size, or even armament may be limited. The Washington Naval Treaty after World War One, for instance, limited both the numbers and sizes of various classes of warships. The size of ships may be limited due to considerations of getting the ship through canals, under bridges, or into drydocks or harbors. More often than not, however, size constraints are attempts to limit cost.

Once a set of requirements (combat capability, size bounds, cost limits, configuration bounds, and minimum mobility limits) are fed to the design team, the ship design process begins. The design team or organization may provide feedback that can in turn affect the requirements. However, once the design requirements are set, and design standards and policies decided upon, the largest step towards defining the subsequent design has been made. Thousands of manhours and several years of design work lay ahead, but these requirement decisions done in pre-concept and concept design serve to eliminate many of the myriad choices available, and begin the design spiral constriction described earlier.

Viewed in this manner, wartime producibility (or 'mobilization design') described in chapter 2 is a subset of the Fleet Concept category of peacetime producibility. That is, if one projects the need for large numbers of warships to escort merchants across the ocean in wartime, the safest procedure would be to build huge numbers of destroyers, and man and train them in peacetime so that they would all be ready at the onset of the conflict. Given the limited budget of the country and the navy, this is unrealistic. Thus the fleet concept considered in replacement may be to build primarily larger, more sophisticated ships in peacetime, but prepare designs for rapid construction in an anticipated prewar environment. Other fleet concepts include Admiral Zumwalt's concept of high mix and low mix, a policy of mixing more sophisticated ships and less sophisticated ones. The suggestions for single-mission ships rather than multi-mission, proposals for commercial standards on some naval ships, and the idea of having a changeable payload (particularly on small, fast patrol boats) are all examples of Fleet Concept. Other examples are the Arapaho concept of rapid, pre-conceived conversion of merchant assets and the whole question of the priorities of life cycle cost versus acquisition cost alluded to earlier. These concepts and others are a valuable means of reducing ship cost by considering not only the ship to be designed as a system, but the task group, or fleet, or navy in which it is to operate as a system.

The fundamental tradeoff is between the option of having a smaller number of highly capable ships versus having higher numbers of less individually capable ships. This decision is closely related to producibility considerations of designing and building smaller numbers of complex, tailor-made ships versus larger numbers of simple ships which are easier to mass-produce. This basic trade-off is made today primarily based on military effectiveness rather than producibility considerations.

3.2.2 Preliminary Ship Layout

Once the design team has been provided with performance requirements and other constraints, it proceeds to develop the design. Many additional trade-offs are studied. Producibility options which impact general arrangements, subdivision, gross dimensions, gross shape, or subsystem selection belong in this Preliminary Ship Layout category, which occurs in the timeframe of feasibility through preliminary to early contract design. The NAVSEA design team is the principal participating party, although the acquisition managers confirm that cost constraints are met and the fleet checks that performance requirements are reached. The dilemma is that the earlier the design phase, the fewer the assets available to investigate options, but the greater is the leverage for substantially affecting the ultimate design. With the recent advances in computer aided ship design, an opportunity is in the offing permitting assessment of a wider variety of options with fewer manpower assets.

Some examples of producibility proposals which should be addressed early in the design process when ship characteristics are still fluid include the use of various materials for hull, superstructure, or piping; various schemes to simplify distributed systems such as cabling and piping; the variation of margins and design standards; the increase of volumetric tightness to reduce ship size and weight; and its antithesis, decrease of volumetric tightness to reduce fit up time and skill and thus reduce labor costs. Almost anything that affects the design could be considered a part of producibility, but the main thrust is to seek either new technology that uses "sophisticated simplicity" to reduce cost, or to choose a simple, rugged solution with current technology that reduces cost, although it may in fact increase displacement or some other more common measure. Appendix A lists some producibility ideas.

The area of Preliminary Ship Layout is the most fertile area for producibility research for the naval ship designer. It is an area where he has substantial control (unlike Fleet Concept). It also occurs early enough in the design cycle to have impressive leverage to affect the ultimate design. Preliminary Ship Layout is further discussed in subsequent chapters.

3.2.3. Production Details

Once the general configuration and layout is decided upon (usually fixed during preliminary design and in some cases by early contract design), the design is refined and additional details developed. This distinctness is analogous to the quick sketch of the artist with a few deft strokes being detailed with later fine, distinct lines, and occurs during contract design and throughout detail design. If the proposed producibility item would not impact general arrangements, gross dimensions, shape, subdivision, or subsystem selection, but will impact component selection, material selection, internal arrangements, and working drawings, then the item belongs in the Production Details category of peacetime producibility. The tolerance guideline is that the change that follows from incorporation of the design option must be 'absorbable' within the fixed ship configuration and within its design and construction margins. These margins are meant to account for the uncertainty of design. The primary participating parties are the NAVSEA design team that typically produces the contract design, and the design agent who refines and defines the contract design into the detail design for the contractor who will eventually build the ship. Often, this category involves dialogue and interaction between the designer and the builder. Some examples of producibility items that fall within the Production Details category include; structural details such as minimizing penetrations in bulkheads and minimizing lightening holes; standardization of structural panels; and simplifying piping runs and fabrication techniques. Certain materials trade-offs, such as the use of glass-reinforced-plastic (GRP) outfitting materials to minimize labor, or the substitution of High Strength, Low Alloy (HSLA) Steel for High Yield Strength (HY-80) Steel also belong in Production Details. HSLA has very similar properties to HY-80, but is far easier to fabricate. Minor palletization might also fall within this category, as a means of easing hookups and causing more shop vice shipboard manhours. The investigation of welding techniques has resulted in many possible labor saving methods.

3.2.4. Shipyard as Factory

If the proposed producibility item is not directly ship design dependent, but rather is a function of the production facility physical plant, then the item belongs in the Shipyard as Factory (SAF) category of peacetime producibility. The primary participating party is the shipbuilder. Some examples of SAF include zone outfitting, in which the ship is outfitted by region rather than by system; modular construction, where worker access and productivity is improved by use of hull modules which are later joined together; the development of test standards that support zone outfitting; computer-aided logistics and material control; computer-aided working drawings, in which only that information required for a construction task appears on the drawing; and production flow optimization. Many of the techniques of the modern production line fit into this category, such as computer-aided manufacturing (CAM); process lanes or group technology, in which similar facets of different products are catalogued for the purpose of grouping together the manufacture of the different parts; and statistical process control, which is a near real-time measure of the effectiveness of the various SAF techniques.

3.2.5. Economic Considerations

If the producibility item is a business or acquisition strategy decision, having less to do with hardware and more to do with scheduling, methods of supply, and contracts, then it belongs in the Economic Considerations category of peacetime producibility. It will have little impact on the ship design and minor impact on the production facilities. These economic considerations can start with the first conceptual study and will not end until the last ship is scrapped. The principal participating parties are the private industry ship builder, the Navy Program Office; and the Congress. Some examples of Economic Considerations are: whether material or equipment should be government furnished or shipbuilder provided; whether it should single- or multi-sourced; what sort of contract should be pursued (fixed price, cost, incentive); and whether shipbuilders should make or buy certain equipment. The learning curve for ship production is an important factor, therefore the decision as to how large a particular ship class or flight should be is vital ("series production"). The location of new production facilities, the availability of labor, and the work load distribution and hire/fire practices are all examples of the Economic Considerations category of peacetime producibility. The statistical management approach is an extension of statistical process control discussed previously, but more management and less manufacturing process oriented.

3.2.6. The Time Frame for Various Categories

The first three categories;

Fleet Concept

Preliminary Ship Layout

and Production Details

are intimately involved in the ship design process, and thus can be identified on a timeline of the ship's conceptualization, design and construction cycle.

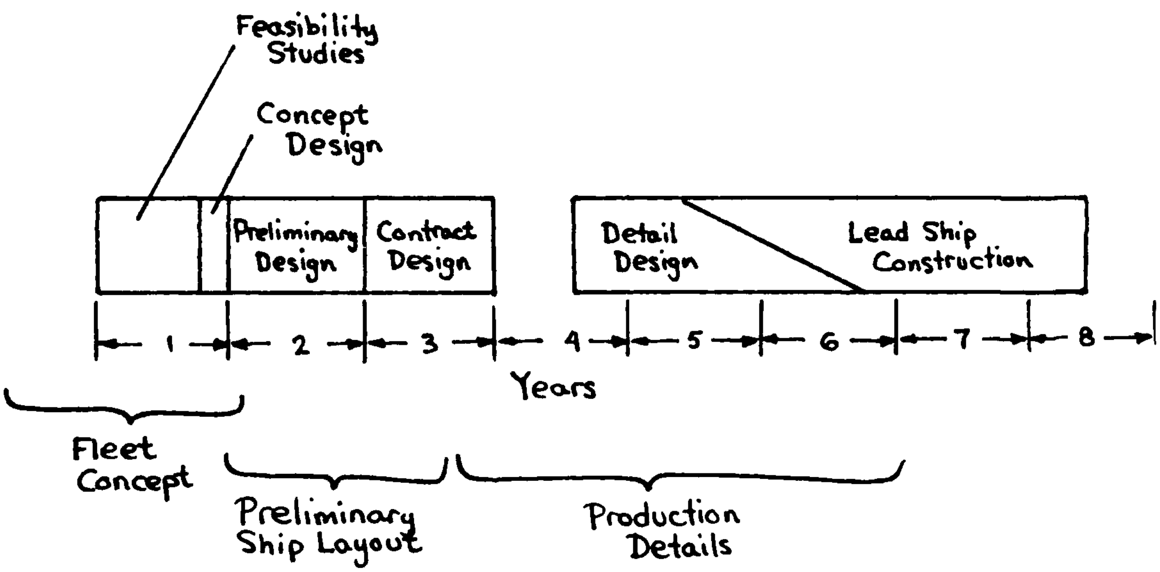


Figure 5: Time Frame for Producibility Categories

The last two categories, Shipyard as Factory and Economic Considerations, are least dependent of a specific design cycle. These decisions could be made as policy before a specific ship acquisition project is initiated and could be finalized anytime during the design process.

3.3 Relationship of Producibility Categories

It will be noticed that some producibility concepts fit easily into a specific category, while some others are on the border between two categories. The categorization is useful in discussing the broad area of producibility. Producibility as a field is still being matured. It has received wide attention of late within the U.S. Navy and the shipbuilding industry as a whole, but has remained somewhat amorphous. Older research material concentrates upon the massive shipbuilding programs of the World Wars. Information on producibility concepts gleaned from these sources can be quite applicable to our peacetime (cost) producibility interests. Since the mid-1960's, the concentration on producibility has been on cost, or as this paper terms it, peacetime producibility. The acceleration of interest in peacetime producibility in the U.S. was slow, but it has hurtled two important milestones. The first milestone was the formation in 1971 of the National Shipbuilding Research Program (NSRP). The Design/Production Integration panel (SP-4) and the Education panel (SP-9) received their first government funding in fiscal year 1982 [3], and are of particular interest to this author as representing a movement from the later three categories of peacetime producibility to now include the earlier category of Preliminary Ship Layout. The second milestone of tremendous importance was the first issue of a quarterly *journal* on ship production, titled "Journal of Ship Production", sponsorerd by the Society of Naval Architects and Marine Engineers and edited by Howard Bunch, NAVSEA Professor of Ship Production at the University of Michigan. The premier issue of February 1985 had a particularly valuable article by L.D. and R.D. Chirrillo which traced the history of modern shipbuilding methods since World War Two.[15] The authors mention four key individuals. The first was Henry Kaiser the industrialist, whose efforts in World War Two were mentioned in Chapter Two. In building Liberty ships alone, Kaiser needed only two-thirds the time to build than the time required by traditional shipbuilders. Of importance to the subject of peacetime producibility was that the cost was 25 percent less as well.[15] After World War Two, the second key individual Elmer Hann took the Kaiser methods to Japan. Mr. Hann had been production superintendent at a Kaiser yard. While Japan's Navy and merchant marine had been decimated, her shipyard facilities were largely intact. National Bulk Carriers (NBC) leased a portion of the former Kure Naval Dockyard in 1951, where Mr. Hann introduced all welded construction. His key methods were:

"1. Careful analysis of vessel as to size blocks and shape with refined drawings or sketches of each weldment, together with machinery, piping, etc. to be installed at assembly shop or area.

2. Coordinated material control.

3. Allocation of labor and time schedule for each operation.

4. Installed machinery, piping, and other equipment to a great extent before erection.

5. Reduced staging to a minimum.

6. Introduced inorganic-zinc coating in the assembly line.

7. The key to rapid construction is how to weld without distortion and shape of weldments or modules that defy or resist distortion especially when such affects the vessel's measurements and locked-in stresses." [15]

The training of middle managers in the entire shipbuilding system was also stressed. By 1964, Japanese yards were producing 40 percent of the world's total shipbuilding tonnage.

The third key individual was Dr. W. Edward Demming, Professor of Statistics at New York University, whose Statistical Control Methods (SCM) were adopted by Japanese industry in the 1950's. The fourth was Dr. Hisashi Shinto, who first worked for NBC under Elmer Hann at Kure. After the NBC lease at Kure expired in 1961, the Kure yard became Ishikawajima-Harima Heavy Industries Co., Ltd (IHI), the leader in shipbuilding methods today (For instance, Bath Iron Works currently utilizes IHI production consultants). Dr. Shinto retired in 1979 as president of IHI, and he developed and refined the Kaiser-Hann-Demming methods, and stressed the need for college educated middle management.

Another important article in the premier "Journal of Ship Production" explained several of the key methods of productivity improvement. Bruce Weiers [95] described systems of modern shipbuilding work organization now evolving:

a. *Process lanes and group technology.* Systematic classification to allow grouping of production.

b. *Zone Outfitting.* The outfitting of the ship by regions rather than by systems.

c. *Staging.* The practice of assembling outfit material prior to assembly of blocks, units, or modules.

d. *Statistical Process Control.* Measurement of process effectiveness to permit process improvement.

It can be seen that various terms are used to represent very similar ideas; *producibility, productivity,* and *modern shipbuilding* methods are all terms fitting under the umbrella term "producibility" that has been used. The last two italicized terms correspond more closely with the last three of the categories outlined in section 3.2, while producibility implies more the involvement of design to ease the scope of the work to be done and to integrate the design and planning with the production. For that reason, as previously stated, the category of Preliminary Ship Layout is seen as crucial for one concerned with producibility as a design factor in naval combatants. The current research in productivity or modern shipbuilding methods has been concentrated in the area of commercial ship construction. However, Mr. Weier states, "Naval combatants are very 'dense' ships . . . This density implies a much higher proportion of outfitting work . . . [however] there appears to be no practical obstacle to the application of advanced shipbuilding concepts developed abroad for building commercial ships to the construction of naval vessels, even combatants."[95] He rightly points out that combat systems and programmatic costs outweigh the cost of the ship platform itself, so that productivity improvements in shipbuilding would be considerably diffused by the time it was reflected in overall ship system cost.

CHAPTER FOUR: PROPOSED PEACETIME PRODUCIBILITY EVALUATION METHODOLOGY

4.1 CURRENT PROCEDURE OF EVALUATION

In the days of total package procurement of ships (LHA, DD 963), shipbuilders were able to incorporate significant producibility features in the design. The pressure of devising a low cost ship to meet stated Navy requirements, combined with the requirement for the preliminary, contract, detailed design and the construction phases within a single organization, gave significant emphasis to 'design for production'. With the recent return of a more traditional ship procurement strategy, no single organization performs the four stages of ship acquisition listed above. The Navy has opted to return to in-house preliminary and contract design, in large part to maintain tighter rein on the performance aspects of the designs. The U.S. Navy is just beginning to explore means of involvement of the ultimate builder in the earlier stages of an in-house design.

The most recent example is the DDG 51 Arleigh Burke class of Aegis guided missile destroyers. As this is written, the contract for the lead ship has just been let, and detail design is beginning. Shipbuilders were assigned producibility studies.[51] These studies were collected in the Surface Combatant Data Bank [116] and represent a valuable resource for future producibility studies. However, no common methodology for evaluating producibility concepts was in existance. No producibility organization existed to assist in this evaluation, so it was created. However, the new personnel in the organization had to (1) learn their new tasks (2) conceive of a method of investigation, and (3) collect producibility data with no foundation to build upon. When funding dwindled, the producibility talent was reassigned to other tasks, and thus this nucleus of producibility expertise was scattered. Many producibility ideas had to be ignored, because by the time they were developed, it was too late for incorporation into the design. Also, some design participants perceived that the shipbuilder's producibility studies had little effect on the design, due perhaps to lack of coordination between the producibility investigators and the mainstream ship design team.[51]

4.2 PROPOSED METHODOLOGY FOR EVALUATION

In order to properly evaluate a producibility concept, the following steps must be accomplished:

(a) gather data and information that characterizes the producibility concept.

(b) perform a ship impact analysis to determine the effect of the incorporation of the producibility concept on the ship characteristics. This could be accomplished by use of marginal weight factors[40], but is generally performed by exercising a design synthesis model.

(c) determine the impact of the producibility concept on the cost of the ship.

(d) determine and evaluate the impact of the producibility concept on the performance of the ship, or in other words, consider and changes in overall ship effectiveness.

(e) evaluate the inherent risk invoked by the incorporation of the producibility concept. This risk could be in the form of technical uncertainty, schedule risk, or lack of confidence in the cost estimates.

After the accomplishment of the above tasks, the data and analysis results must be presented to the decision maker in a format that emphasizes the key issues. The items important for judging the merit of the producibility concept, either alone against the baseline or in synergism with other concepts, must be present in a form that aids the decision making process. An excess of data is also undesirable, in that the key points will lose their significance if buried in a myriad of non-critical items.

The ideal evaluation model would perform steps (b), (c), (d), and (e) of the methodology proposed above, but in actuality only the ship impact can be analyzed by the Producibility Assessor using today's typical synthesis model. Recent design synthesis models have an integral cost analysis capability, but the current ones are all very limited.

4.3 DESIGN SYNTHESIS AS A DESIGN TOOL

The virtues and possible perils of design synthesis models have been ably written of, but the arguments condense to this. The speed of calculation and depth of calculation of design synthesis models allow an order of magnitude higher number of design alternatives to be investigated and compared. However, the parametric nature of early (and most current) design synthesis models encourages designs similar to previous designs, and thus discourages innovation in the already conservative field of ship design. Investigation of a wide range of synthesis models verifies these observations.

Synthesis Model	Source	
Simplified Math Model	MIT Design Course	Manual (calculator) model for naval frigates
Spreadsheet Simplified Math Model	self	Above model made slightly more flexible and considerably faster, programmed on the CPM spreadsheet 'Supercalc'.
Reed Synthesis Model	MIT Thesis (1976)	Mainframe computer FORTRAN program for surface combatants.
ASSET (Advanced Surface Ship Evaluation Tool)	Boeing Computer	Monohull version, recently installed at MIT on a VAX mainframe within the Joint Computer Facility.
ISPAM (Ingalls Ship Producibility Analysis Model)	Ingalls	Microcomputer version recently installed in the MIT Ship Computer Aided Design System.

Table 3: Frigate/Destroyer Synthesis Models Investigated for Producibility Applicability

With the concentration on naval frigate/destroyer type models, mention must be made of DD08, currently in use at the Naval Sea Systems Command (NAVSEA). It is not available at MIT, and thus was not examined.

ASSET (Advanced Surface Ship Evaluation Tool) was selected as the most suitable tool for producibility investigations. It was in fact designed for technical innovation evaluation, and requires extensive expertise in naval architecture and ship design to utilize properly. To perform a synthesis design, the Ship Designer is a necessary link in the iterative loop (dashed loop in figure 6). The automatic, internal synthesis of ASSET (solid loop in figure 6) achieves a balance of ship weight and ship displacement by modification of the hull's sinkage, without any adjustment to hull geometry or hull structure. The analysis modules are assessment tools, used by the ship designer for his manual adjustment before the next iteration. The analysis modules do not alter the current ship image within the synthesis model as do the computional modules.

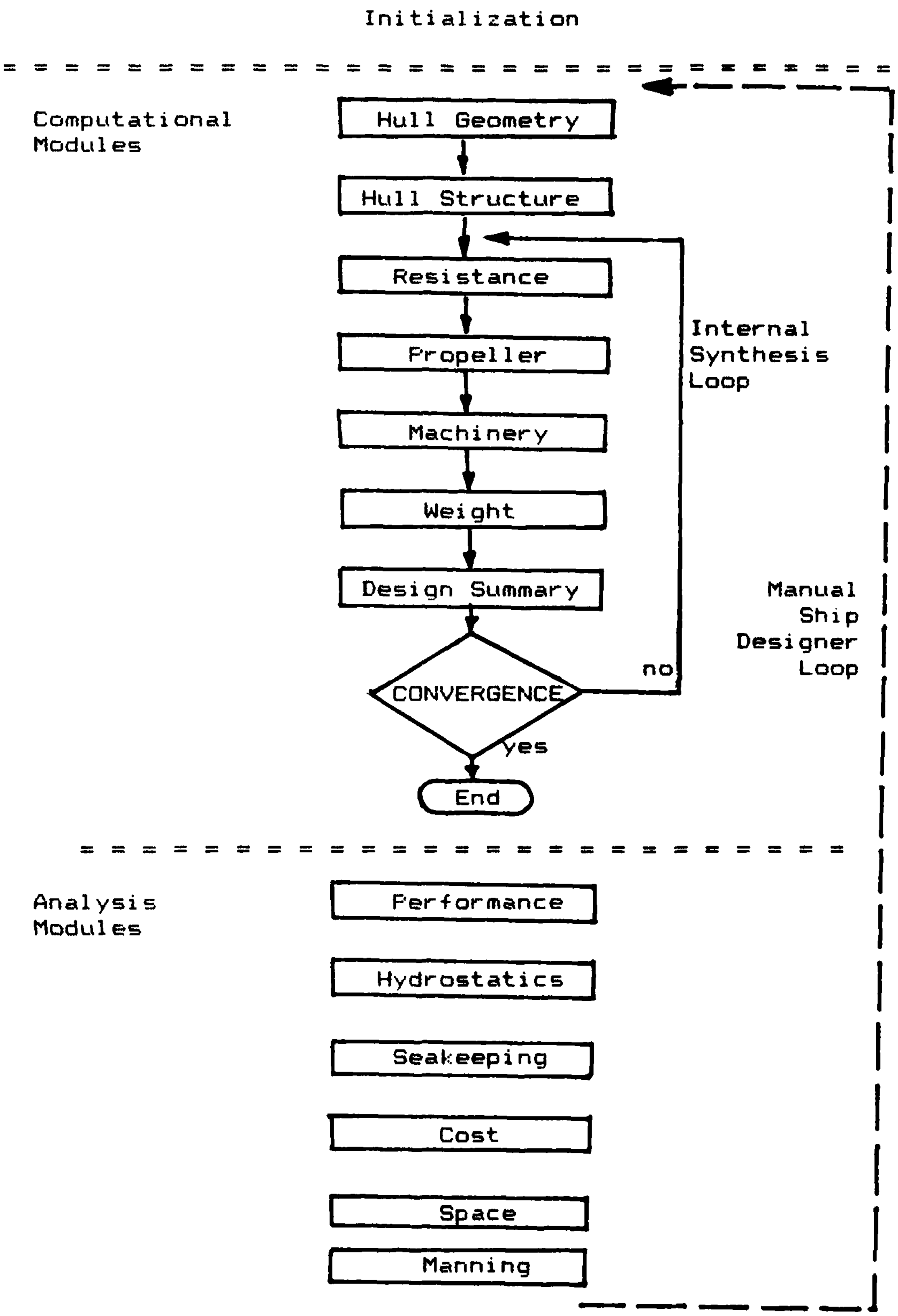


Figure 6: ASSET Monohull Surface Combatant Logic [20]

Despite the state of the art status of ASSET, the Cost Analysis Module is termed 'interim' and is quite limited. It considers only a one digit weight breakdown for cost evaluation. ISPAM is a much more limited synthesis model, able to handle only *minor* variations around the baseline CG 47 class ship. However, its costing methodology is suitable for use in peacetime producibility studies, and the marriage of these two programs should be seriously considered.

ASSET was utilized for the case studies which appear in chapter 5, with an enhancement of the existing cost analysis module. The cost analysis module is, by virtue of the arguments presented in chapter 3, crucial to peacetime producibility assessmant.

4.4 IMPACTS TO CONSIDER

The primary impacts to consider in peacetime producibility evaluations are: *primary ship characteristics* (size, mobility, power, manning), *cost* (acquisition and operation/support), *risk* (technical and programmatic), and *effectiveness* (primarily combat effectiveness).

4.4.1 Ship Characteristics

The following ship characteristics were selected for impact assessment.

Length at waterline

Length between perpendiculars

Beam at waterline

Hull Depth amidships

Draft

Full Load Displacement

Hull Volume

Deckhouse Volume

Total Volume (the above two added)

Some measure of stability (GM/B was selected)

Total Electrical Load

Main Engine Continuous Propulsion Power Available

Maximum Sustained Speed

Endurance Speed

Range

Manning

Payload

Margins

Additionally, it was decided to break down the weights to the one-digit Ships Work Breakdown System (SWBS) level. Udo Rowley's current MIT Thesis [86] provides the philosophy and specification definition to implement a comparative naval architecture module within ASSET, and his work will be useful for more detailed comparison of ship characteristics when implemented.

4.4.2 Cost

Cost, particularly acquisition cost, is the very keystone of effective peacetime producibility assessment. The ASSET interim cost analysis is sorely limited. The ISPAM costing methodology is excellent, but its proprietary nature and narrowness of focus (CG 47) prevented its utilization in this thesis. Therefore, a supplement for the ASSET cost analysis was programmed on a micro-computer spreadsheet, the commercial program Supercalc.

The cost estimating enhancement effort is intended to illustrate the potential gain to be realized from the implementation of an improved costing module within ASSET. The current method within ASSET for determination of acquisition cost is to multiply a one digit SWBS weight by a Cost Estimating Ratio (CER) to get the cost of that one digit portion of the ship. The degree of definition of the costing scheme should be increased in two dimensions. The one digit weight should be subdivided into the two- or three- digit level, so that relatively small producibility proposals that affect only a particular sub-element of the ship can be measured against the baseline for total cost impact.

Similarly, the overall CER should be broken into components of material cost, direct labor costs, and program labor costs to allow evaluation of producibility proposals which affect these varied cost aspects in different ways. For this demonstration of the enhancement required of the cost analysis, the breakdown was carried out to a semi-two digit level in weight groups 1,2,and 3. These three weight groups together typically account for about half of the light ship weight of a naval frigate. The overall CER was broken down to a separate consideration of material and labor costs, with direct and program labor lumped together for this demonstration. These trends of further weight breakdown and CER differentiation should be continued. The CER numbers selected in the chapter 5 case studies are considered reasonable, but further collection of cost data with the aim of validating these figures and relating CER's to other weight sub-groups should be done.

4.4.3 Risk

The evaluation of risk is an undeveloped field. The current practice remains to designate 'high', 'medium' or 'low' risk, by subjective means. Quantitative measures of risk that incorporate the degree of risk, deviation analysis, and the time frame considerations do not exist. However, investigation is progressing, and Sean Walsh's MIT Thesis on the subject [94] is a proposal for a more quantitative risk analysis and classification. In this study, subjective risk assessment is used, despite its limitations, for lack of anything better.

4.4.4 Effectiveness

Quantitative effectiveness measures are rare, and when they exist, they do not excite universal confidence. Dr.

Dean Rains has done considerable pioneering work in the area of effectiveness assessment [77]. The measure of effectiveness is so crucial to the assessment of cost-effectiveness (an alternate term for peacetime producibility) that further research is likely to be forthcoming. In this producibiliy assessment, effectiveness was maintained a constant insofar as possible. However, the final assessment of a producibility concept should include a means to mention relative combat system effectiveness, mobility, survivability, and operability, as they are the primary elements of a naval warship's effectiveness. The judgements will necessarily be subjective in this study, and thus effectiveness is another area that calls for future investigation.

4.5 EVALUATION METHODOLOGY

The methodology for peacetime producibility outlined in this thesis centers around the evaluation of the detailed cost of ships and the integration of this costing within the existing design synthesis tool. The ASSET design synthesis model has been utilized in conjunction with an enhanced costing analysis implemented on a micro-computer spreadsheet. The methodology has been exercised on several producibility concepts in the following chapter, and is best explained by example. It is oriented to the rubber-ship type studies in which the design has not yet been locked in any parameters. The use of ASSET indicator options allows simple conversion of a baseline to paper-ship (a later phase of design where certain parameters are locked) or existing-ship (conversion) investigation purposes.

The evaluation methodology consists of focusing attention on four presentations of information. These presentations are summarized on the following four pages:

Page 1: Producibility Concept Definition

Page 2: Ship Characteristics Impact

Page 3: Ship Cost Impact

Page 4: Summary

A sample page is provided in figures 7 through 10. Each of the four Producibility Assessment pages is discussed below, and suggestions for two future pages are included.

Page one is the Producibility Concept Definition, where a description of the proposed producibility concept is provided. This page would also include a discussion of changes to geometry, weight, volume, and cost. The top half of the page is the direct impact analysis, provided by a study by a subsystem designer. This study could be on the order of the producibility studies performed by shipbuilders for DDG 51.[116] Page one would be filled out for each producibility concept being proposed for a certain type of ship and would be kept on file. This first page also features specifics concerning the intended rebalancing of the variant after the incorporation of the direct impacts. Many indirect or second order changes are handled within ASSET, but some are

Figure 7: PRODUCIBILITY ASSESSMENT, page 1

Producibility Concept Definition Ship:__________ Item:__

Concept:____ Ref:___

Description and direct (first order) changes. Include weight,volume,cost,geometry,power,manning.

Tradeoffs between baseline and concept variant. Where will the concept gain and lose?

baseline

variant

Translation to Assessment Tool

Record of ASSET Changes . . . item | baseline | variant

(1)
(2)
(3)
(4)
(5)
(6)
(7)
(8)
(9)
(10)

Rebalancing Comments:

Figure 8: PRODUCIBILITY ASSESSMENT, page 2

Ship Characteristics Impact   Ship:_________   Item: ___
Concept:____

parameter	abbrev(dim)	baseline	variant	delta	percent
Length at waterline	LWL (feet)				
Length between perpendiculars	LBP (feet)				
Beam at waterline	B (feet)				
Depth amidships	D (feet)				
Draft	T (feet)				
Displacement, full load	Δfl (LT)				
Volume of hull	∇h (k ft^3)				
Volume of deckhouse	∇dh(k ft^3)				
Total Volume	∇t (k ft^3)				
Stability measue	GM/B (-)				
Total electical load	KW tot (KW)				
Main contin. power available	IP (hp)				
Manning	N (men)				
Maximum sustained speed	Vs (kts)				
Endurance speed	Ve (kts)				
Range	R (nm)				
Payload	W payld(LT)				
Margins	-----------				

SWBS Group					
100 Hull Structure	W1 (LT)				
200 Propulsion Plant	W2 (LT)				
300 Electrical Plant	W3 (LT)				
400 Command and Surveillence	W4 (LT)				
500 Auxiliary Systems	W5 (LT)				
600 Outfit and Furnishings	W6 (LT)				
700 Armament	W7 (LT)				
Weight of D+B margin	Wm (LT)				
	===========	======	======		
LIGHTSHIP WEIGHT	W ltshp(LT)				
Fuel & Lubricant weight	Wf (LT)				
Ordnance Load weight	Wa (LT)				
Other Load weight	Wo (LT)				
	===========	======	======		
FULL LOAD WEIGHT	W fl (LT)				

Weight of primary 2-digit SWBS . . .

name	subgroup
-----------------	--------
-----------------	--------

note:small apparent summation errors are due to display roundoff.

Figure 9: PRODUCIBILITY ASSESSMENT, page 3

Ship Cost Impact (FY85 $) Ship: _________ Item:___

Concept: ____

SWBS No.	Description	------- Baseline Weight	CERm	----- CERh	------ Variant Weight	CERm	------ CERh	Baseline Cost,k$	Variant Cost,k$	k$ delta	percent
11/12/13	HullMatl A										
11/12/13	HullMatl B										
15	DkhsMatl A										
15	DkhsMatl B										
162	Stacks										
171	Masts										
1X	Rest,Grp 1										
23 (hp)	Propul Units										
241	Reduc Gear										
243	Shafting										
244	Bearings										
245	Propellers										
25	Support Sys										
26	Sup Sys-FO,LO										
2X	Rest,Grp 2										
31 (hp)	ElecPowerGen										
32	Power Distrib										
3X	Rest,Grp 3										
4	Command										
5	Auxiliary										
6	Outfit & furn										
7	Armament										
	D&B Margin										
	LIGHT SHIP		na	na		na	na				
8	Engineering	ditto			ditto						
9	Assembly	ditto			ditto						
ACQ.CONSTRUCTION COST		na	na	na	na	na	na				

Weights for alternate costing SWBS No.

SWBS No.	Description	Baseline	Variant
23	Propul Units		
31	ElecPowerGen		

SWBS No.	Description	Baseline	Variant	%
11/12/13	Hull Matl$			
15	Dkhs Matl$			

ACQ.CONSTRUCTION COST
plus profit %:

ACQ.CONSTRUCTION PRICE
plus change orders
plus NAVSEA support
plus post delivery
plus outfitting
plus H/M/E + growth
plus payload cost

UNIT SAILAWAY ACQ COST (k$)
OPER+SUPPORT SYSTEM COST ($M)
AVG LIFE CYCLE COST/ship ($M)

notes: acquisition costs are for follow ship.O+S and LCC are for 30 ships w/ 30 year life.

Figure 10: PRODUCIBILITY ASSESSMENT, page 4

Summary Ship:__________ Item:__

Concept:____

Impact	Comments	baseline better (-------		equal		------- variant better)	
Weight	____________________ ____________________	¦	¦	¦	¦	¦	¦
Volume	____________________ ____________________	¦	¦	¦	¦	¦	¦
Stability	____________________ ____________________	¦	¦	¦	¦	¦	¦
Elec Power	____________________ ____________________	¦	¦	¦	¦	¦	¦
Manning	____________________ ____________________	¦	¦	¦	¦	¦	¦
Combat System Effectiveness	____________________ ____________________	¦	¦	¦	¦	¦	¦
Mobility	____________________ ____________________	¦	¦	¦	¦	¦	¦
Survivability	____________________ ____________________	¦	¦	¦	¦	¦	¦
Operability	____________________ ____________________	¦	¦	¦	¦	¦	¦
Acquisition Cost	____________________ ____________________	¦	¦	¦	¦	¦	¦
Operating and Support Costs	____________________ ____________________	¦	¦	¦	¦	¦	¦
Life Cycle Costs	____________________ ____________________	¦	¦	¦	¦	¦	¦
Risk	____________________ ____________________	¦	¦	¦	¦	¦	¦
Other:______________	____________________ ____________________	¦	¦	¦	¦	¦	¦

Bottom Line:____
____

not. These second order changes not handled within ASSET include manning, main deck sheer line, and stability, and they must be incorporated manually by the user, with the assistance of analysis modules. Drawings within the boxes on this first page help clarify the producibility concept to a decision maker reviewing the Producibility Assessment.

Page two assesses the Ship Characteristics Impact, changes in geometry, power, stability, manning, weight, and volume. Weight is detailed to the one digit SWBS level. The parameters chosen for comparison are shown for both the balanced baseline and the balanced variant incorporating the proposed producibility concept. The differences (deltas) and the percentage difference are noted for each parameter. The percentage difference is the delta divided by the baseline value of the parameter.

Page three is the Cost Impact. Ship weight, carried to a greater level of detail than in the original ASSET cost analysis, is used to derive most costs. In some cases an element of the ship acquisition cost might be better correlated to volume, but no cost data was available to verify this. However, horsepower is used to estimate cost for both main propulsion and electrical power generation. Cost estimating ratios (CER) are divided between material and manhour costs, and yield costs in thousands of dollars for a follow ship. The orientation is towards acquisition cost, as befits today's political appropriation climate, but the ASSET analysis of life cycle cost is included as well.

At this point, if the investigations into risk assessment and effectiveness evaluation could support analysis of these areas, a page for each would be devised on the model of the previous two pages. However, as discussed in sections 4.4.3 and 4.4.4, there is a large amount of work to be accomplished in these fields before such a methodical and standardized procedure can be formulated for risk and effectiveness. Therefore, risk and effectiveness are handled subjectively for now and appear in the final summary sheet of the Producibility Assessment without analysis sheets of their own. Both of these areas are fertile ground for ongoing investigation.

For the stand alone assessment of a particular producibility concept against the baseline, the data presented on pages two and three may appear excessive for presentation to a decision maker. However, they serve as a ready backup of data to support the conclusions reached in the summary page, page four. The level of detail presented in pages two and three are absolutely a requirement for assessment of the synergistic impacts of two different producibility concepts against one another.

Page four of the Producibility Assessment is the Summary, where the most important impacts are displayed and compared, advantages and disadvantages of the concept are briefly explained, and a final recommendation as to the worth of the producibility proposal is made. The key display on this page is the comparison of whether the baseline or the variant is better in the most important impact areas. Some of these comparisons are supported by specific numbers: weight, volume, stability, electric power, manning, mobility, and the various varieties of cost. Even those assessments supported by computed deltas and percentage changes are subject to the design philosophy of the producibility assessor. For instance, the overriding philosophy adhered to in the case studies of chapter 5 is that the minimum cost ship system that meets the design requirements (considering ship characteristics impact, risk, and effectiveness) is the superior choice. Specifically, low weight and volume is better, but low cost for a high weight-generating concept would dominate on the final producibility assessment. The ability to later add weight high on the ship is desirable, so a higher GM/B is generally better, although too stiff a ship is undesirable. Low electrical power and manning is desirable. The underlined items in Producibility Assessment sheet page four, figure 10, are considered the impact elements of most importance to the peacetime producibility assessor. Combat system effectiveness and mobility together represent the bulk of overall ship effectiveness. Acquisition cost is at the very core of peacetime producibility assessment, as discussed in chapter 3. Risk is a gauge that can determine whether the concept ever reaches actual construction and validification.

The amount of acceptable risk varies considerably for the ship program. For a research/demonstration ship such as the now retired reasearch submarine Albacore or the current 200 ton surface effect ship (SES 200), certain forms of risk may be even desirable as they are a form of mission effectiveness for that ship. The amount of acceptable risk for a thirty ship combatant class will be considerably lower, and must be balanced against the potential gain.

The Proposed Producibility Evaluation Methodology is demonstrated in the following chapter on several concepts. The process would be made more convenient by the incorporation of a comparative analysis module within ASSET [86], by the creation of an even more detailed cost analysis than described here, and by the automatic collection of the data within an ASSET producibility assessment analysis module based upon these principles.

Several changes to ASSET would aid future investigators, in particular:

(a) A method of redefining the shear line of the hull without manually altering the hull offsets (a time-consuming task).

(b) A means of defining angle of flare, not only for the deckhouse angle, but also for the hull.

(c) An option for defining the deckhouse in various ways. Currently it is locked into the deck edge geometry; an option for it to remain the same size or to fit a needed volume requirement by an 'expandable' section would be convenient.

(d) A menu specifically for balancing purposes, with weight and displacement, required volume and actual volume, stability and seakeeping all on a single screen. Currently, at least three screens must be displayed for each iteration.

(e) A means of doing a preliminary check on general arrangements, primarily for large object spaces in relation to hull dimensions and bulkheads. A useful bonus would be an option of printing out blank deck diagrams for more detailed, manual arrangement studies.

In conclusion, the establishment of a Producibility Assessment Methodology is new. The method proposed above for peacetime producibility assessment appears reasonable and will be exercised in the following chapter.

CHAPTER FIVE: EVALUATION OF PEACETIME PRODUCIBILITY CONCEPT

5.1 BASELINE FOR CASE STUDY

A producibility proposal from the peacetime, Preliminary Ship Layout category was evaluated using the proposed methodology. The study was performed using ASSET (Advanced Surface Ship Evaluation Tool, Monohull Surface Combatant Version). The baseline is an adaptation of a baseline by C. Goddard [35] which in turn is an adaptation of a large ASW Frigate design for an MIT Design Course.

The Battle Group ASW Frigate (BGASWFF) baseline ship ("RUBBER.BL.BAL"), listed in Appendix D, was altered to orient it more to unconstrained ("rubber ship") conceptual studies. The frigate has an Anti-Submarine Warfare (ASW) oriented payload with a heavy conformal sonar array, a long towed array, and vertical launch ASROC, Harpoon, and Seasparrow. Three Lamps III helicopters are carried and maintained aboard. The hull form is a Hull 23 variant, and the material for both hull and superstructure is High Tensile Steel (HTS). The baseline frigate has two gas turbine prime movers driving twin fixed pitch propellers through an electric, water cooled AC/AC transmission. Four gas turbine generators, partial CPS, and anti-roll fins complement this seakeeping and ASW optimized form. The gross characteristics are as listed in Table 4:

Length between perpendiculars	426.9 feet
L/B ratio	8.5
Full Load Displacement	5558 long tons
Payload weight	675 long tons
Sustained speed	27.95 knots
Endurance	4500 nm at 20 knots

Table 4: Gross Characteristics of Baseline BGASWFF

Further details of the baseline are contained in the case studies and Appendix D. Charles Goddard's thesis [35] should be consulted for further background information on the development of the baseline.

5.2 Producibility Concept: Deck Height Reduction by Reverse Framed Deck

The three major factors affecting deck height are: [116]

- personnel headroom requirements
- system envelopes
- deck structural envelopes and structural continuity

Personnel Headroom

U.S. Navy specifications require 77 inches of headroom on surface ships and permit 75 inches of headroom on submarines. [116]

System Envelopes

These system envelopes include local ventilation ducting, cooling, water piping and cabling. In the system-crowded electronics spaces, the overhead system envelope is adequate at six inches. [116] The bulk of cabling will be run either under equipment and walkways or under a false deck in false-decked major electronics spaces, and systems are primarily in the overhead in the more conventional spaces with false decks (passageways and the bulk of other spaces).

Deck Structural Envelopes and Structural Continuity

The above three major factors affecting deck height have been traditionally translated in structural arrangement which places main structural deck plating over a mainbeam (See Figure 11). The plating is stiffened against buckling by deck stiffeners cut and welded between deck webs. False decks are utilized in certain electronics spaces having massive cabling; typically radar rooms, communications center, combat information center (CIC), and sonar control.

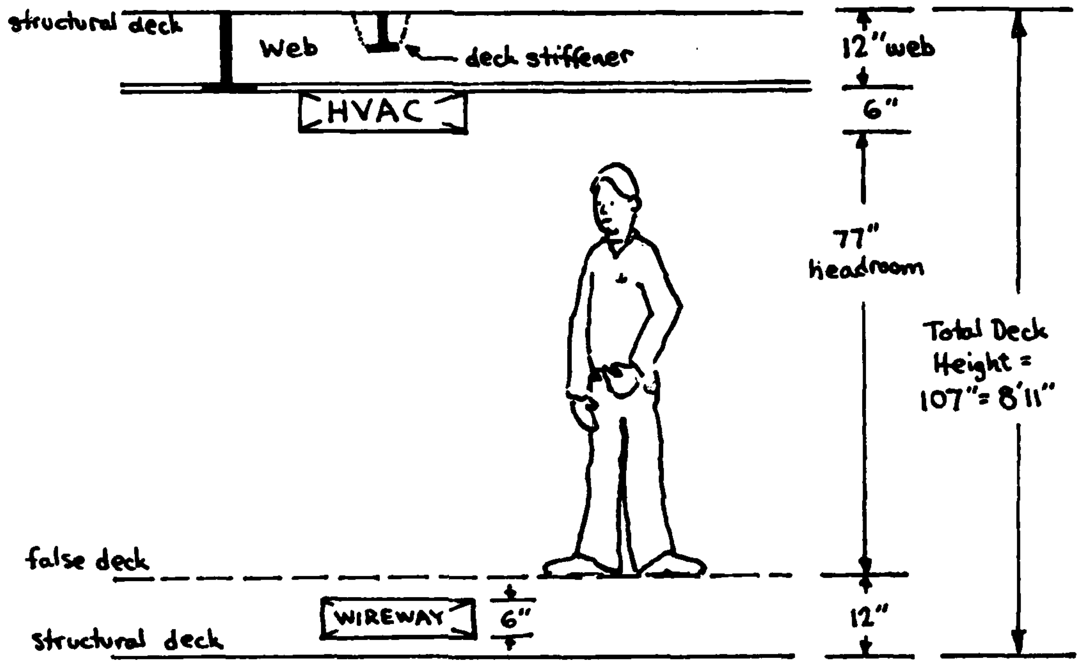


Figure 11: Conventional Framed Electronics Deck

The false decked electronics spaces are critical as they are typically near amidships, and the lack of any false deck requirement in other spaces (passageways and non-electronic spaces) provides sufficient headroom in these spaces amidships and hull sheer (fore & aft) also provides additional headroom and available system envelope volume above.

An alternative 'reverse framed deck' has been proposed. [116] In this scheme the mainbeam is <u>above</u> the structural deck and the deck stiffeners are <u>below</u> the structural deck; that is, the transverse deck stiffeners and the longitudinal deck stiffener are on opposite sides of the structural deck they support. Having structural tees at the feet of personnel is acceptable only in that the required false deck creates a flat walking surface (See Figure 12).

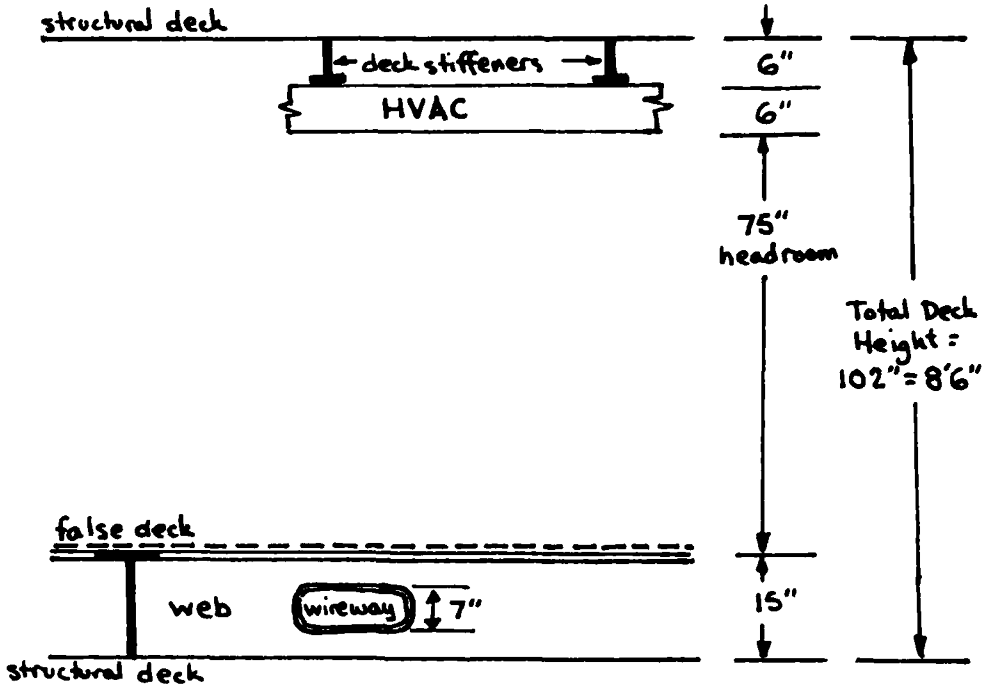


Figure 12: Reverse Framed Electronics Deck

For the purposes of this study, it is assumed that there is a common deck height throughout the ship (allowing deck heights to vary from deck to deck and restricting false decked electronics spaces to decks with suitable deck heights is a valid potential producibility study, but is not examined in this thesis.)

The baseline ASW frigate has a deckhouse average deck height of 8'6" and a hull average deck height of 8'6" also, having incorporated the lessons of DDG-51 deck height studies and utilized reverse framing and 75-inch (submarine standards) headroom in the major electronics spaces. What is the overall producibility assessment of changing deckheights from this innovative deckheight arrangement to a more conventional 9'0" average deck height in both the hull and deckhouse?

Using Producibility Assessment Sheet page one (Figure 13), the producibility concept is cataloged and the direct or first order changes entailed are described. The tradeoffs section gives the Assessor-to-be and Decision Makers preliminary notice of areas to monitor in the analysis to follow. The two boxes allow a sketch to be made of the baseline and variant, or the area can alternatively be used for a data table that particularly illustrates the concept. The latter half of the form is the producibility assessor's notes of how he translated the concept to the assessment tool in use (ASSET with substituted cost analysis module). The rebalancing comments clarify the change records. However, the Translation to Assessment Tool section is limited in size. It is sufficient to show the decision maker the parameter selections made in evaluating the producibility concept, and provide a concise record of the changes to the baseline.

Producibility Assessment Sheet page 2 (Figure 14) lays out the impact of changes in ship's characteristics, and goes more deeply into weight impacts. The numbers in the baseline and variant columns are rounded off in the display, but the additional significant figures are retained within the internal workings of the spreadsheet for the delta (change from baseline to variant) and percent column calculations. The spreadsheet program listing for Producibility Assessment Sheet page 2 is provided as Appendix B.

Figure 13: PRODUCIBILITY ASSESSMENT, page 1

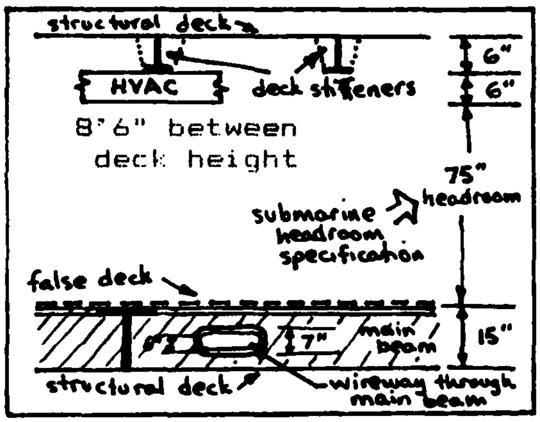
Producibility Concept Definition Ship: _BGASWFF__ Item: _1

Concept: _Deckheight_reduction_w/_reverse_framing___ **Ref:** 116

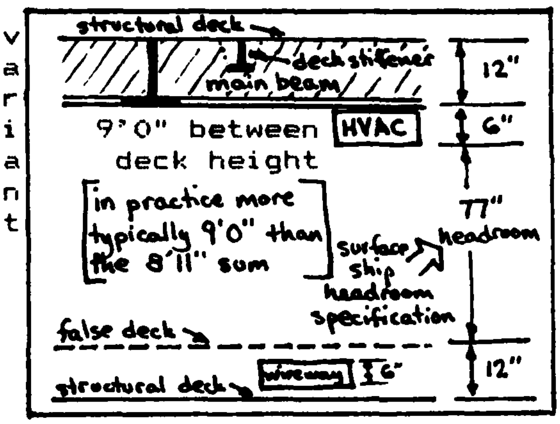
Description and direct (first order) changes. Include weight, volume, cost, geometry, power, manning.
By using submarine headroom standards (75") and reverse framing (transverse stiffeners and longitudinal stiffeners on opposite sides of the structural deck they stiffen) deck-height in critical false decked electronics spaces can be reduced from 9'0" to 8'6". System envelopes (wireways, HVAC) remain constant at 6" deep each, weight stays the same, the material cost is constant, labor costs of the reduced deck-height version is 5% higher (cutouts in main beam for stiffeners in variant approx equal to cutout for wireway for the baseline. No manning or power changes.

Tradeoffs between baseline and concept variant. Where will the concept gain and lose?
The reduced deckheight will reduce overall ship volume, and the smaller ship should cost less. However, the slightly increased labor costs of the 9' variant will offset this some. Headroom suffers only in elex spaces (77"->75").

baseline



variant



Translation to Assessment Tool

Record of ASSET Changes . . . item	baseline	variant
(1) Hull Deck Location Array	29.5.21,12.5,4	29,20,11,2 *
(2) Deckhouse Height Array	8.5,17,8.5,8.5	9,18,9,9
(3) Deckhouse Average Deck Ht	8.5	9.0
(4) Hull Matl A CER for manhrs	4.6	4.52 **
(5) Deckhs Matl A CER for manhrs	7.4	7.22 ***
(6)		
(7)		
(8)		
(9)		
(10)		

Rebalancing Comments: *After intial balance, adjust up for increased hull size. ** Deck 36% of Hull Matl A. ***Deck 50% of total deckhouse. (sample: .36 x .05 = .018; 1/1.018 = .982 CERmb = 4.6 x .982 = CERmv = 4.52) baseline=RUBBER.BL.BAL

Figure 14: PRODUCIBILITY ASSESSMENT, page 2

Ship Characteristics Impact   Ship: BGASWFF   Item: 1
Concept: Deckheight Reduction w/ reverse framing; baseline=8'6", variant=9'0"

parameter	abbrev(dim)	baseline	variant	delta	percent
Length at waterline	LWL (feet)	427	430	2.80	.66
Length between perpendiculars	LBP (feet)	427	430	2.80	.66
Beam at waterline	B (feet)	50	51	.33	.66
Depth amidships	D (feet)	38	38	.25	.65
Draft	T (feet)	18.83	18.96	.13	.69
Displacement, full load	Δ fl (LT)	5558	5669	110.20	1.98
Volume of hull	∇h (k ft^3)	558	569	11.06	1.98
Volume of deckhouse	∇ dh(k ft^3)	108	116	7.92	7.30
Total Volume	∇t (k ft^3)	667	686	18.98	2.85
Stability measue	GM/B (-)	.1027	.0989	.00	-3.70
Total electical load	KW tot (KW)	4105	4133	28.10	.68
Main contin. power available	IP (hp)	52209	52514	305.00	.58
Manning	N (men)	301	301	.00	.00
Maximum sustained speed	Vs (kts)	27.95	27.95	.00	.00
Endurance speed	Ve (kts)	20.00	20.00	.00	.00
Range	R (nm)	4500	4500	.00	.00
Payload	W payld(LT)	970	970	.00	.00
Margins				.00	

SWBS Group	abbrev(dim)	baseline	variant	delta	percent
100 Hull Structure	W1 (LT)	1305	1370	65.30	5.00
200 Propulsion Plant	W2 (LT)	429	434	4.70	1.10
300 Electrical Plant	W3 (LT)	252	256	4.10	1.63
400 Command and Surveillence	W4 (LT)	650	651	1.20	.18
500 Auxiliary Systems	W5 (LT)	640	650	10.80	1.69
600 Outfit and Furnishings	W6 (LT)	397	403	6.50	1.64
700 Armament	W7 (LT)	130	130	.00	.00
Weight of D+B margin	Wm (LT)	475	487	11.60	2.44
LIGHTSHIP WEIGHT	W ltshp(LT)	4278	4382	104.20	2.44
Fuel & Lubricant weight	Wf (LT)	1010	1016	5.90	.58
Ordnance Load weight	Wa (LT)	144	144	.10	.07
Other Load weight	Wo (LT)	127	127	.00	.00
FULL LOAD WEIGHT	W fl (LT)	5558	5668	110.20	1.98

Weight of primary 2-digit SWBS . . .

name	subgroup	baseline	variant	delta	percent
Shell and supports	110	389	443	54.20	13.93
Deckhouse structure	150	158	173	15.10	9.56

note:small apparent summation errors are due to display roundoff.

The percent change column is determined by dividing the delta by the baseline. Any percentage change less than one half of one pe cent is considered negligible.

Many of the items are taken directly from ASSET menus.

	module	menu
Length at waterline	Hydrostatic Analysis	1
Length between perpendiculars	Design Summary	1
Beam at waterline	Design Summary	1
Draft	Design Summary	1
Displacement, full load	Design Summary or Hull Geometry	1 1
Volume of hull ("actual")	Space Analysis	1
Volume of deckhouse ("actual")	Space Analysis	1
Total Volume ("actual")	Space Analysis	1
Stability measure (GM/B)- transverse	KM from Hull Geometry KG from Design Summary B from Design Summary	1 1 1
Total Electrical Load	Design Summary	1
Main Cont. Power Available	Sum engines, Design Summary	1
Manning	Design Summary	1
Max. Sustained Speed	Design Summary	1
Endurance Speed	Design Summary	1
Range	Design Summary	1
Payload	Design Summary	4
Margins	Design Summary	3
Weights	Weight Module	1

Table 5: Source Within ASSET of Ship's Characteristics

The weight of primary 2 digit SWBS subgroups is based on the Evaluator's estimate of primary weight impacts of the producibility proposal. They are obtained from Weight Module menus two through nine, depending on the concept's impact.

Producibility Assessment Sheet page 3 (Figure 15) provides an alternative to the cost analysis currently resident in ASSET. The spreadsheet program listing is provided as Appendix C. The replacement acquisition cost analysis breaks weight group down beyond the one-digit level used in ASSET, and breaks the CER (cost estimating ratio) into material (CERm) and manhour or labor (CERh) components. Neither of these breakdowns is the ultimate; rather, both breakdowns should be further expanded. Ultimately, the weight breakdowns for cost should be at the same semi three-digit level of detail as ASSET's weight module menus 2 through 9 provide. The next logical progression for CER breakdown would be to separate the labor component into direct and program labor.

The deckheight reduction example in Figure 15 is interesting in that the percentage effect on the reduction on weight is greater for the hull than for the deckhouse, but this is reversed in regards to cost. That is, the percentage increase in cost is greater for the deckhouse than for the hull.

The cost numbers are in thousands of dollars, and the main derivatives to compare are the Acquisition Construction Cost, its delta between the baseline and variant, and its per-

Figure 15: PRODUCIBILITY ASSESSMENT, page 3

Ship Cost Impact (FY85 $) Ship: BGASWFF Item: 1

Concept: Deckheight reduction w/ reverse framing; baseline=8'6", variant=9'0"

SWBS No.	Description	Baseline Weight	Baseline CERm	Baseline CERh	Variant Weight	Variant CERm	Variant CERh	Baseline Cost,k$	Variant Cost,k$	k$ delta	percent
11/12/13	HullMatl A	875.9	3.6	4.6	920.9	3.6	4.52	7182	7478	295.328	4.11
11/12/13	HullMatl B	0	0	0	0	0	0	0	0	0	.00
15	DkhsMatl A	158.3	5.5	7.4	173.1	5.5	7.22	2042	2202	159.762	7.82
15	DkhsMatl B	0	0	0	0	0	0	0	0	0	.00
162	Stacks	31	5.5	7.4	32.8	5.5	7.4	400	423	23.22	5.81
171	Masts	10.7	5.5	7.4	11.3	5.5	7.4	138	146	7.74	5.61
1X	Rest,Grp 1	228.8	2.9	4.3	231.9	2.9	4.3	1647	1670	22.32	1.35
23 (hp)	Propul Units	52209	.41	.15	52512	.41	.15	29237	29407	169.68	.58
241	Reduc Gear	0	6	4	0	6	4	0	0	0	.00
243	Shafting	78.7	31	4	79.7	31	4	2755	2790	35	1.27
244	Bearings	14.6	32	4.5	14.8	32	4.5	533	540	7.3	1.37
245	Propellers	31.8	2	4	31.9	2	4	191	191	.6	.31
25	Support Sys	65.2	50	10	67.2	50	10	3912	4032	120	3.07
26	Sup Sys-FO,LO	24.7	35	9	24.8	35	9	1087	1091	4.4	.40
2X	Rest,Grp 2	10.7	30	5	10.7	30	5	375	375	0	.00
31 (hp)	ElecPowerGen	4105	.86	.63	4133	.86	.63	6116	6158	41.72	.68
32	Power Distrib	92.8	20	40	95.3	20	40	5568	5718	150	2.69
3X	Rest,Grp 3	63.2	20	40	64.2	20	40	3792	3852	60	1.58
4	Command	650.2	15.6	23	651.4	15.6	23	25098	25144	46.32	.18
5	Auxiliary	639.6	28.5	19.3	650.4	28.5	19.3	30573	31089	516.24	1.69
6	Outfit & furn	396.9	12.3	24.2	403.4	12.3	24.2	14487	14724	237.25	1.64
7	Armament	130	3.6	7	130	3.6	7	1378	1378	0	.00
	D&B Margin	475.3	35.9	0	486.9	35.9	0	17063	17480	416.44	2.44
	LIGHT SHIP	4277.7	na	na	4381.9	na	na	153573	155887	2313.32	1.51
8	Engineering	ditto	0	6.62	ditto	0	6.62	28318	29008		
9	Assembly	ditto	0	9.02	ditto	0	9.02	38585	39525		
ACQ.CONSTRUCTION COST		na	na	na	na	na	na	220477	224420	3943	1.79

Weights for alternate costing SWBS No.

SWBS No.	Description	Baseline	Variant
23	Propul Units	203.3	204.6
31	ElecPowerGen	96	96.6

SWBS No.	Description	Baseline	Variant	%
11/12/13	Hull Matl$	3153.24	3315.24	5.14
15	Dkhs Matl$	870.65	952.05	9.35

	Baseline	Variant	k$ delta	percent
ACQ.CONSTRUCTION COST	220477	224420	3943	1.79
plus profit %: 8	17638	17954	315	
ACQ.CONSTRUCTION PRICE	238115	242373	4258	1.79
plus change orders	19049	19390	341	
plus NAVSEA support	5953	6059	106	
plus post delivery	11906	12119	213	
plus outfitting	9525	9695	170	
plus H/M/E + growth	23811	24237	426	
plus payload cost	276200	276200	0	
UNIT SAILAWAY ACQ COST (k$)	584559	590073	5515	.94
OPER+SUPPORT SYSTEM COST ($M)	31221	31289	68	.22
AVG LIFE CYCLE COST/ship ($M)	1706	1711	5	.29

notes: acquisition costs are for follow ship.O+S and LCC are for 30 ships w/ 30 year life.

centage difference in cost between the baseline and variant. The builder's profit is not reflected in the Acquisition Construction Cost, but is included in the Acquisition Construction Price. The Sailaway Cost reflects the profit, the payload cost (constant), and change orders, NAVSEA support costs, post delivery charges, outfitting, and growth. The Operating and Support Cost and the Life Cycle Cost are from the ASSET analysis, and are indicated in millions of dollars ($M) vice thousands of dollars (k$) for all the acquisition costs.

The actual CER's selected need to be verified. The data on naval ship costing is usually kept secretive, but what is important is the relative cost between the different aspects of building a ship (material vs. labor, propulsion vs. hull, etc.), and not necessarily the actual dollar figure. The comparison in cost between the various aspects of the total ship is important for producibility assessment.

Producibility Assessment page 4 (figure 16) is a summary of the results of the peacetime producibility concept analysis. The most important impacts are laid out in a format that allows a visual weighing of the overall merits of the variant as compared to the baseline. Several of the impacts (combat system effectiveness, mobility, acquisition cost, and risk) are underlined as being of particular importance. Several of the listed impacts, for example weight, are supported by specific numerical figures and percentages in the

Figure 16: PRODUCIBILITY ASSESSMENT, page 4

Summary

Ship: BGASWFF Item: 1

Concept: Deckheight reduction w/ reverse framing

Impact	Comments	baseline better <-------		equal		-------> variant better
Weight	variant weighs more		X			
Volume	variant:vol deficient	X				
Stability				X		
Elec Power				X		
Manning				X		
Combat System Effectiveness				X		
Mobility				X		
Survivability				X		
Operability	lower overhd in BL could limit rigging access				X	
Acquisition Cost	due reduced size of the baseline		X			
Operating and Support Costs	baseline better, but not statis. significant			X		
Life Cycle Costs	BL better, but not statistically signif.			X		
Risk	both are low risk. variant is standard practice			X		
Other: BL concept: some question re: transition from false deck to non-false-deck. However, difference in height is only 3" more than the variant.				X		

Bottom Line: The baseline, with 8'6" deckht, is almost 2% better in acq cost w/ no significant penalties.

previous assessment pages. In this deckheight example, the lighter weight baseline is evaluated as slightly better in weight impact than the variant. This correlation is based on the philosophy that smaller is better, that an option that meets the requirements with less assets is the superior option. It must be kept in mind that other impacts could dominate; for example, if an option weighed more but required significantly fewer manhours, it would likely prove to be an overall better choice. For instance, a different deckheight producibility concept could be to <u>increase</u> the deckheight, allowing a greater depth for the systems' envelope, and thus allowing less labor intensive fitting of the systems into the envelope. The tradeoff between deckheight reduction and deckheight addition will result in a deckheight that corresponds to the minimum cost/maximum effectiveness point.

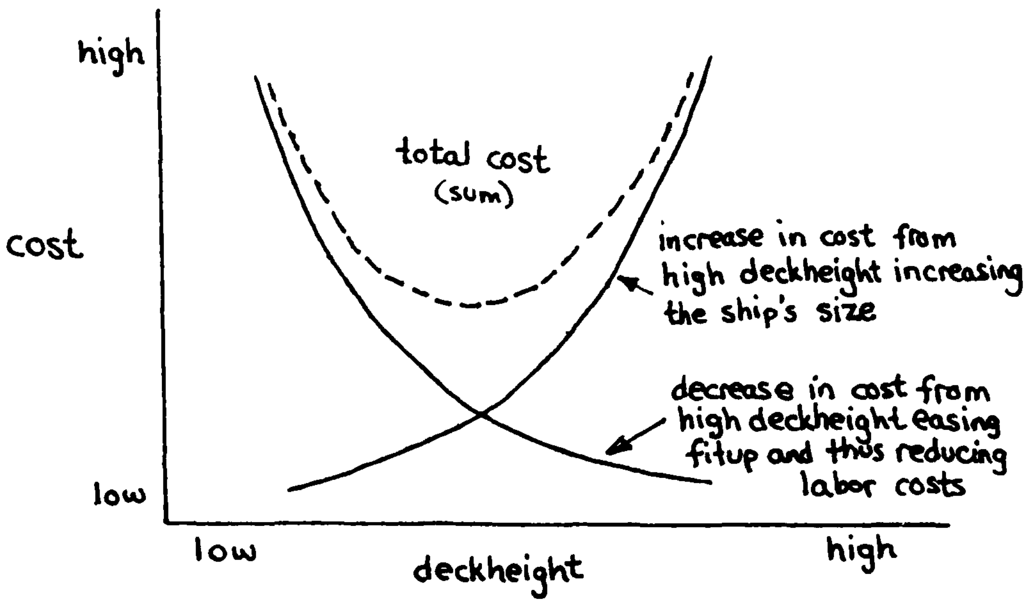


Figure 17: Theory of Deckheight Determination

The overall determination of deckheight will be based upon many deckheight studies, of which the study performed in this thesis is but one. The study herein, for example, held system envelope depth constant, and assumed all deckheights in the ship were the same.

This single deckheight reduction study, as evaluated in figure 16, assesses the baseline with the reduced 8'6" deckheight as better in weight, volume, stability, and the crucial acquisition cost parameter. The 9' deckheight variant was judged slightly superior in operability due to rigging considerations. Overall, the baseline was assessed as significantly better than the variant.

CHAPTER SIX: U.S. NAVY PRODUCIBILITY ORGANIZATION

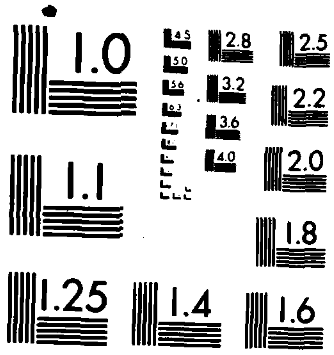
6.1 OUTLINE OF ORGANIZATION

The previous chapters have outlined the differences between wartime (schedule-critical) and peacetime (cost-critical) producibility. A first step has been taken with the development of a peacetime producibility assessment methodology. However, as stated in the introductory chapter of this thesis, combatant ship design is complex and is accomplished by a myriad of individuals within large organizations. Creation of a new office is not to be recommended lightly; certainly the existing organization is large and complex enough. However, existing offices have their developed policies, priorities, and goals, and these are not easily altered to encompass a new task, particularly when funding and manning is barely adequate for tasks already delegated.

Therefore, in order to provide impetus to producibility design within the U.S. Navy, to provide continuity of purpose, and to develop producibility talent and tools, a new office within the Naval Sea Systems Command (NAVSEA) should be brought into being. This organization would be led by the Ship Producibility Advocate, who would direct the three pronged efforts of the new organization. The three primary responsibilities of the new office would be:

(a) producibility data compilation.

AD-A159 011   PRODUCIBILITY AS A DESIGN FACTOR IN NAVAL COMBATANTS   2/3
(U) MASSACHUSETTS INST OF TECH CAMBRIDGE DEPT OF OCEAN
ENGINEERING M L BOSWORTH JUN 85 N66314-70-A-0073
UNCLASSIFIED   F/G 13/10   NL


1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

(b) wartime producibility projects coordination.

(c) apportionment of producibility talent to design projects. Within the matrix organization of NAVSEA, the new producibility organization would be primarily functional (vice project) oriented. Actual design would be accomplished within NAVSEA 05 as before, but the ship design project would be assigned producibility assessors from the producibility organization. The new office would coordinate with other mobilization entities within the Department of Defense and the Maritime Administration and press for the major wartime producibility objectives of detail design and prototypes of austere combatants.

6.2 SHIP PRODUCIBILITY ADVOCATE

The Ship Producibility Advocate would be resident within NAVSEA, and would be tasked with the development of an organization with responsibility for:

(a) collection of data on producibility concepts, ship construction time (including component lead time), and ship costs.

(b) development of a wartime producibility assessment methodology and design/schedule assessment tool.

(c) compilation of a continually updated and evolving library of austere wartime producible detail designs.

(d) continuation of the development of the methodology and producibility assessment tool outlined herein for peacetime producibility.

(e) provision of personnel for ship acquisition project producibility teams.

(f) collection of feedback from detail design agents, construction shipyards, repair facilities, and the fleet for the purpose of enhancing the producibility of the design at the earliest possible stage.

(g) the publishing of a Producibility Manual to formalize the incorporation of producibility as a major spoke in the design spiral for U.S. Navy combatants.

6.3 DATA COLLECTION

As a beginning in the arduous task of collecting the direct impact (first order) producibility data, two resources are contained in this thesis. The first is an annotated bibliography. This bibliography is in a form suitable for a simple microcomputer database, and contains keywords for concept search and an abstract of each reference. Certain magazines will be particularly useful in expanding this producibility database, namely the Journal of Ship Production and the Naval Engineer's Journal. Foreign publications should also be sought. Of note are articles published by the Royal Institute of Naval Architects (RINA). The two index publications of the SNAME Ship Production Committee, [106] and [123], and the NAVSEA Surface Combatant Data Bank [116] would combine with the published articles to form a credit-able start to a producibility database.

The importance of the cataloguing system (i.e. category and keywords) cannot be overstated. One cataloguing scheme is contained in reference [106], which emphasizes the later producibility concepts (production details, shipyard as factory). The cataloguing scheme used in the annotated bibliography attempts to be more broadly based to encompass earlier phases of design. However, the bibliography cataloguing scheme should be considered as merely a starting point for a new and more detailed breakdown of categories.

The second resource contained in this thesis for data collection is a list of producibility ideas (Appendix A) with references.

CHAPTER SEVEN: CONCLUSIONS AND RECOMMENDATIONS

The past decade has seen an increased awareness within the United States concerning the methods utilized in designing, planning, and constructing ships. The National Shipbuilding Research Program (NSRP) and the stated intention of national leaders to increase the Navy's size to 600 active ships focuses the need for improved producibility in naval combatant ships. Considering the broadness of ship producibility as a subject, little has been written to give a sense of order to the myriad of issues involved. This thesis strives to give some form to this larger context of 'ship producibility', and then focuses in on the area of 'design for production'.

7.1 WARTIME vs. PEACETIME PRODUCIBILITY

There are two major classifications which are useful for focusing attention on the subject of ship producibility.

a. Wartime Producibility: In wartime, or in a prewar mobilization environment, the primary objective is to produce ships in the *least amount of time.* Schedule is of the essence, and the task of constructing a large number of ships in time to affect the outcome of the conflict takes overwhelming precedence. It is concluded that the Navy should create a series of highly producible, standard ship designs tailored for rapid construction in the nation's second echelon shipyards. The designs should be carried to the detailed design stage, and prototypes for each class of ship should be produced to validate and mature the construction working plans. These prototype ships would serve in the reserve forces in peacetime and concentrate on developing tactics for use by their wartime, mass-produced brethren.

b. Peacetime Producibility: In the peacetime environment, the objective is to produce the ships required to maintain an effective 600 ship peacetime Navy at the *least cost*. The production cost of ships can be reduced through increased efficiency in the design, construction, testing, and fleet introduction process. The primary effort of this study has been directed towards the subject of peacetime producibility.

7.2 CATEGORIES OF PEACETIME PRODUCIBILITY

As an aid in conceptualization, peacetime producibility has been divided into five broad categories:

a. Fleet Concept (pre-concept design determination of fleet mix, ship mission and requirements).

b. Preliminary Ship Layout (conceptual through preliminary design sizing, subsystem selection, and tradeoff studies).

c. Production Details (contract and detailed design elements that do not affect ship characteristics and subsystem selection).

d. Shipyard as Factory (function of the production facility physical plant and its interface with the design. Decisions in this category might be made independent of a specific project.)

e. Business Considerations (business/acquisition strategy and material supply. To be considered throughout the entire span of the ship's conceptualization, design and production cycle.)

The first three categories lie approximately in the chronological order in which they fall within the vessel's conceptualization, design, and production cycle. Current producibility research efforts are being concentrated in the latter three categories (notably by the NSRP), and these efforts are beginning to bear fruit. Part of a ship designer's attention should be in support of producibility categories c, d, and e. However, the earlier in the design cycle the decision authority considers producibility in a real and quantifiable manner, the greater is the leverage commanded. It is suggested that category b, Preliminary Ship Layout, is the area in which the ship design community should concentrate its immediate innovative energies.

7.3 PRELIMINARY SHIP LAYOUT

Little progress has been made to date in the area of Preliminary Ship Layout. Producibility has been addressed during the Navy inhouse design phases of recent designs (FFG-7, CG-47, and DDG-51), but there was no in-place, rigorous evaluation procedure available to assess the tradeoffs associated with producibility concepts. Data on ship producibility concepts had to be regenerated for subsequent ship design projects. The U.S. Navy's future frigate (FFX), with studies currently underway for a ship to be built around the turn of the century, is the next major target of opportunity. There is significant leverage in enhancing the cost/effectiveness of naval ships by adopting producibility concepts early in the design process.

7.4 PRODUCIBILITY EVALUATION METHODOLOGY

A procedure for rigorous evaluation of ship producibility concepts during the early phases of the ship design process has been developed and contains the following recommendations:

a. A rigorous evaluation methodology is required to assess the overall ship impact of the proposed producibility concepts. The term "overall ship impact" is taken to mean the change in *ship characteristics* (volume, weight, electrical power and manning), the change in *ship cost* (acquisition, operating and support), the change in *ship effectiveness*, and the change in technical *risk*.

b. A combined design/cost synthesis model is the primary tool required to determine the ship characteristics and ship cost impacts in the earliest design stages (before preliminary design). In early preliminary design, a synthesis model is used by varying the baseline and comparing alternatives. In later preliminary design and thenceforth, manual calculations are utilized. The Advanced Surface Ship Evaluation Tool (ASSET), developed at David Taylor Naval Ship Research and Development Center, has been selected as the best design synthesis model for expansion into a true producibility assessment model.

c. Data on producibility concepts needs to be accumulated and catalogued to facilitate design team determination of overall ship impact (characteristics, cost, effectiveness, and risk). This would allow selected producibility concepts to be integrated into the ship design. Concepts should be catalogued as to their effect on ship's characteristics and the phase of design in which a commitment decision need be made.

d. A Handbook for Ship Producibility should be produced which describes the evaluation methodology and provides the catalogue of producibility concepts. This Handbook should be provided to each new ship acquisition program.

e. An Advocate for Ship Producibility should be established within the Naval Sea System Command. This advocate, among other responsibilities, would catalogue all existing producibility concepts, develop and maintain the producibility assessment tools, maintain the Handbook for Ship Producibility, and provide required staff to assist new ship acquisition projects.

The developed Ship Producibility Evaluation Methodology has been exercised on a producibility concept to demonstrate its utility. This thesis deals primarily with the earliest stage of design, when one evaluates concepts on a ship in which the characteristics are still fluid ("rubber ship"). Later stages of design, when one deals with a ship with final characteristics ("paper ship"), would vary considerably from ship to ship and involve more manual calculations. General rules for later stages of design can, however, be inferred from the "rubber ship" type studies. The producibility model uses the existing monohull version of ASSET to determine the ship characteristics and operating/support cost impact. An enhancement program for acquisition cost demonstrates the worth of further cost breakdown for producibility assessment.

The Methodology:

a. Provides a format for collecting information required to evaluate the producibility concept.

b. Determines ship characteristics impact and cost impact by redesigning a baseline ship. Ship performance parameters (mobility, combat systems, survivability and operability) are normalized, and are evaluated in the Methodology only in those cases where ship performance cannot be held absolutely constant.

c. Produces an overall producibility evaluation for help in deciding the utility of a particular producibility tradeoff option.

d. Breaks down this overall criteria into sub-areas, so that searches for synergistic combinations of producibility options can be effectively made.

7.5 RECOMMENDATIONS FOR FURTHER INVESTIGATION

Attention to producibility concerns in the earliest phases of naval ship design, through use of a design synthesis model and real-time cost estimating, can significantly reduce the acquisition cost of the vessels. The need for further investigation for both the wartime and peacetime categories is acute, and opportunities abound in the burgeoning field of producibility. They include:

a. *Detailed analysis of how ship costs are estimated*, and how costing methodologies can be improved through utilization of computer models to permit evaluation of a larger number of producibility concepts. For example, costing based upon piping or wiring run lengths would permit comparison between various general arrangements.

b. *Study of naval mission effectiveness.* This is a difficult area, and design literature is littered with brave attempts at quantifing effectiveness. However, effectiveness is so much at the core of the naval designer's task that further efforts must be made. Perhaps an approach that 'normalizes' the effectiveness evaluation to the particular decision makers then in power could prove fruitful.

c. *The evolution of risk assessment* beyond current 'high', 'medium' or 'low' ratings. Work is in progress in this area, most recently by Sean Walsh of M.I.T.[94] Again, it may prove necessary to provide flexibility in the risk assessment methodology to accomodate the current decision maker's philosophy.

d. *The study of alternate ship production facilities.* The Maritime Administration has done recent work in this area, but primarily focuses on merchant ships. A reevaluation with an eye toward naval combatant ship construction in second and third echelon facilities could prove invaluable, and indeed would be a major spoke in the design cycle of wartime-producible ships.

e. *Specific wartime-producible warship designs.* A corollary to these designs would be investigations of wartime missions that could be assumed by wartime-producible designs.

f. The development of a *methodology for assessment of the schedule impact of design decisions* for wartime-producible ship designs, in conjuction with production decisions.

ANNOTATED BIBLIOGRAPHY

The following format is followed:

Author(s):	Last name first listing with multiple authors separated by semicolons.
Title:	Books underlined and articles in quotes.
Mag/Publ:	The magazine in which the article appeared, the publisher of the book, or the source of the article if unpublished. Abbreviations are listed in Table 6.
Date:	Month/Day/Year
Pages:	Rough count of number of pages to indicate the extent of the article. An improvement would be to indicate the numbers of word or the number of blocks of 100 words, as the number of words per page varies significantly from source to source.
Category:	As proposed in this thesis: (1) Wartime (2) Fleet Concept (3) Preliminary Ship Layout (4) Production Details (5) Shipyard as Factory (6) Economic Considerations with two additions: (7) General; for multiple categories or about ship design in general (8) History; self explanatory The above categorization emphasizes producibility as design factor rather than the overall topic or productivity.
Keywords:	Up to three keywords for search within a simple microcomputer database. A multiple word keyword has the two segments joined with a diagonal slash line.
Abstract:	Some adapted from the abstract within the article, but mostly the compilation of the key points of the reference, in the opinion of one reader.

This bibliography does not claim to be comprehensive, even within the specialized field of producibility design. However, it does serve to point out that producibility concepts can be found in a wode variety of sources, and can serve as a starting point for additional research or for a more extensive compilation of producibility references. For the neophyte reader in this area, permit me to recommend references [14] [15] [30] [39] [51] [89] [106] and [116] as particularly useful.

Table 6: Magazine/Publisher Bibliography Abbreviations

AIAA (American Institute of Aeronautics/Astronautics)
American Machinist
Aviation Week
ASE (Association of Scientists & Engineers of the Naval Sea System)
Business Week
Current Opinion
Engineering
High Speed Surface Craft
Industrial Eng. (Industrial Engineering)
Iron Age
Journ. Ship Prod. (Journal of Ship Production (SNAME))
Life
Marine Eng. Log (Marine Engineering Log)
Material Handling Eng. (Material Handling Engineering)
Metal Progress
Monthly Labor Review
Naval Architect
Naval Eng. Journal (Naval Engineer's Journal (ASNE))
Popular Science
Proceedings
Proc. IEEE (Proceedings of the Institute of Electrical and Electronics Engineers)
Science
SNAME (LS) (Society of Naval Architects and Marine Engineers, local section paper)
SNAME Trans (Society of Naval Architects and Marine Engineers Transactions)
Trans. RINA (Transactions of the Royal Institute of Naval Architects (UK))
Time
Welding Journal

[1] Author(s): Andrews, David
Title: "Creative Ship Design"
Mag/Publ: Trans. RINA Date: 3/81 Pages: 25
Category: Priminary Ship Layout
Keywords: Design Innovation
Abstract: This paper discusses the nature of ship design, computer aided design and its pitfalls, and innovation in ship design. The author proposes how Computer Aided Design could be applied to explore significant changes to ship internal layout, and that a review of new general techniques and design theories could produce an open and creative design philosophy to serve the ship designer of the future. In the tradition of RINA, significant comment is included.

[2] Author(s): Atkinson, Paul
Title: "Shipbuilding Costs Can Be Reduced"
Mag/Publ: Marine Eng. Log Date: 5/61 Pages: 4
Category: Shipyard as Factory
Keywords: Cost Standards Labor
Abstract: Primarily discusses reduction of capital cost of merchant vessels built in U.S. yards. Shipbuilding costs are divided into four fundamental elements of the ship's sale price: material, labor costs, overhead charges, and profit margin. Areas for action are detailed: paperwork, plans & specifications, American standards of construction, design changes during construction, standardization of vessels, competition, shipyard workload, and shipyard problems such as tooling, interchange of information. Also discusses some fertile future fields: lighter structures, working drawings, computer applications.

[3] Author(s): Barham, F. Baxter
Title: "The SNAME Ship Production Committee - Overview"
Mag/Publ: Journal Ship Prod. Date: 2/85 Pages: 25
Category: General
Keywords: SPC
Abstract: This paper describes the SNAME Ship Production Committee (SPC) formed in 1970, and discusses its history and organization, and projects underway by the various panels. Of particular interest is Panel SP-4 and its Design for Production Manual in progress. The NSRP Bibliography and Microfiche Index (with abstracts) is listed in its entirety.

[4] Author(s): Baskerville, J.; Whiddon, D.
Title: "Ship Design - Performance Through Innovation"
Mag/Publ: Naval Eng. Journal Date: 2/81 Pages:11
Category: Preliminary Ship Layout
Keywords: Innovation Design Impact
Abstract: The authors present a 'cost effective frigate' design with a COGOG plant and construct all of aluminum. They discuss innovation assessment, and conclude that cost impacts of performance requirements must be assessable on a subsystem level.

[5] Author(s): Benford, Harry
Title: "Short Cuts in Ship Cost Studies"
Mag/Publ: Marine Eng. Log Date: 4/59 Pages: 2
Category: Economic Considerations
Keywords: Cost Merchant Speed
Abstract: Discusses streamlined engineering economy studies as aids in ship design. The author points out that only four major cost factors have any effect on optimum merchant speed. The are: cargo rate, fuel oil cost, cost of installed machinery, and crew wages.

[6] Author(s): Bohlander; Preiser
Title: "New Technology Antifouling Paints: U.S. Government Research and Assessment"
Mag/Publ: Naval Eng. Journal Date: 7/84 Pages: 7
Category: Preliminary Ship Layout
Keywords: Resistance Paint Hull
Abstract: This paper discusses new antifouling paints featuring organometallic polymer (OMP) toxicants designed to extend ship operating cycles by delaying marine growth. It describes several ship trials now underway, and new trends in this technology are discussed.

[7] Author(s): Bosley, Donald
Title: "The Secret to Japanese Shipbuilding Success: It Can Work in America"
Mag/Publ: Naval Eng. Journal Date: 10/67 Pages: 4
Category: Economic Considerations
Keywords: Management
Abstract: This paper discusses the work of Ryoji Nishijima in man-hour scheduling. It summarizes that with only minor changes, shipyards producing 3000 tons per month increased to production of 10,000 tons per month using this management tool.

[8] Author(s): Boylston, John; Ross, Jonathan
Title: "Shipbuilding Should Turn Inland"
Mag/Publ: Journ. Ship Prod. Date: 2/85 Pages: 10
Category: Production Details
Keywords: Alternate Yards Standards Inland
Abstract: This paper explores the idea of constructing oceangoing vessels at inland yards and provides some comparisons between the inland yards and their coastwise competitors. Data on depth of waterways in the eastern U.S., existing inland yard capabilities, and comparison estimates by coastwise and inland yards on a bulker/tanker and on a 365 foot cruise ship is provided.

[9] Author(s): Brand; Huffstutler
Title: "Productivity Improvements in Two Fabricated Metals Industries"
Mag/Publ: Monthly Labor Review Date: 10/83 Pages: 7
Category: Shipyard as Factory
Keywords: Valves Piping
Abstract: The economist author traces rise and fall of productivity in the valve and pipe fitting industries. Recent increases are attributed to technological advances in metal-working machinery in this small lot production industry. Group Technology is also given credit.

[10] Author(s): Brown, David; Andrews, David
Title: "Warship Design to a Frice"
Mag/Publ: Naval Architect Date: 1/81 Pages: 3
Category: Fleet Concept
Keywords: Cost Austere Single/purpose
Abstract: This paper discusses the design of cheap limited role naval designs to augment sophisticated existing tonnage. Experience indicates that the cheap, multi-role ship is not only inferior in each role but also very expensive. The authors suggest a simple, specialist ship, discuss 1 digit weight and cost breakdowns for R.N. ships, and emphsize the ruthless management necessary to resist the corporate temptation to improve the basic ship.

[11] Author(s): Brown, David
Title: "Productivity Improves at Rolls-Royce"
Mag/Publ: Aviation Week Date: 8/24/81 Pages: 3
Category: Shipyard as Factory
Keywords: Inspection Engine
Abstract: Describes significant productivity gains by Rolls-Royce in the company's large aircraft engine plant. Average increases of 25% per worker are touted since 1978, due to quality circles, design-production interface, structured supervision, standardized tools/-methods, and shifting of some responsibility for quality work to the production worker (vice inspectors).

[12] Author(s): Bullock, Ottis; Oldfield, Brian
Title: "Production PHM Design-to-Cost Hull Structure"
Mag/Publ: AIAA Date: 9/76 Pages: 9
Category: Production Details
Keywords: Cost Weight Hull
Abstract: This paper is a presentation of detail design and fabrication problems and attendent cost/weight effective solutions for the Patrol Hydrofoil (missile). The PHM 1 leadship used miniature structural sections, close stiffener spacing, and tailoring of many structural elements to save weight which resulted in poor weld accessability, weld distortions, and excessive fit-up. Redesign of bulkhead details and plating resulted in substantial cost savings (32% cost savings on bulkhead) and overall fewer parts, less welding, and greater percentage of mechanized welding.

[13] Author(s); Campbell, James
Title: "Value Engineering in Shipbuilding"
Mag/Publ: Engineering Date: 11/10/67 Pages: 1
Category: Production Details
Keywords: Cost
Abstract: Examples of production details from Fairfields Limited of Glasgow. The examples included: vents on cabin doors from wood to steel, cable fasteners, and stapling vice screwing.

[14] Author(s): Carss, David; Vaughan, Roger
Title: "Design for Production"
Mag/Publ: SNAME (LS) Date: - Pages: 21
Category: Production Details
Keywords: Merchant Design
Abstract: Discusses the integration of Ship Design and Production from a commercial ship standpoint, and discusses detailed work necessary: hull geometry, block breakdowns, machinery arrangement relation to blocks, and pipework. The authors give a methodology of design for production.

[15] Author(s): Chirillo, L.; Chirillo, R.
Title: "The History of Modern Shipbuilding Methods: The U.S.- Japanese Interchange"
Mag/Publ: Journ. Ship Prod. Date: 2/85 Pages: 6
Category: History
Keywords: Kaiser Statistical Group/technology
Abstract: The story of how shipbuilding leadership crossed the Pacific westward after WWII is told with four key individuals: Kaiser, Hann, Deming, and Shinto. Basic group technology principles, emphasis on welding without distortion, and educated middle management enabled Japan to capture 40% of world market by 1964 using pre-WWII shipyards. Statistical methods furthered and strengthened the shipbuilding lead. Only a massive education program in the U.S. will suffice to make U.S. shipbuilding competitive again.

[16] Author(s): Clarke, Horace D.
Title: Cost Leverages in Ship Design
Mag/Publ: Naval Eng. Journal Date: 6/76 Pages: 10
Category: Preliminary Ship Layout
Keywords: Leverage Cost Margins
Abstract: The central theme is the determination of cost leverages for "Design-to-Cost" savings. Reduction in design margins, practices, and criteria offer practical cost savings. He states that the principle DTC issue is to determine what is to be given up to reduce cost, and that the cost leverage of individual decisions decreases as the design is defined. His figure 2 illustrates this point; first characteristics, then margins, innovations, practices, and equipments, each with subsequently less leverage.

[17] Author(s): Connery, Robert
Title: <u>The Navy and the Industrial Mobilization in WWII</u>
Mag/Publ: Princeton Univ. Press Date: 1951 Pages: -
Category: Wartime Producibility
Keywords: Series/production
Abstract: In the 5 year period from 1 Jul 1940 to 30 Jun 1945, 19+ billion dollars were spent to construct and equip ships in the U.S. ($8 bilion for ship construction and repair, $4.5 billion for arms and ammo, and $4 billion for radar). Additions in those years amounted to 10 BB, 18 CV, 9 CVL, 110 CVE, 2 CB, 10 CA, 33 CL, 358 DD, 504 DE, 211 SS, and 82k landing craft. 80k aircraft were also acquired at a cost of $8 billion.

[18] Author(s): Dallas, A.; Garbe, G.; Toman, R.
Title: "Designing a Naval Frigate - With the Aid of Hindsight"
Mag/Publ: SNAME (LS) Date: 10/23/82 Pages: 66
Category: Preliminary Ship Layout
Keywords: FFG-7 Design Frigate
Abstract: Current frigate design philosophies regarding growth margins, transverse stability, longitudinal strength, weapons suites, hull form, main propulsion and auxiliary machinery, habitability requirements, stabilization alternatives, builder's costs and warship aesthetics are discussed, based on FFG-7 experience. Alternative parameters for preliminary frigate design are offered. An FFG-7 derivative design is explained which is CODOG, twin screw, and somewhat heavier.

[19] Author(s): Dawson, Christopher
Title: "Propulsion Options for Fast Ferries"
Mag/Publ: High Speed Surface Craft Date: 6/84 Pages: 9
Category: Preliminary Ship Layout
Keywords: Propulsion Diesel
Abstract: Provides significant data on available small, high speed diesels, comparing output, rev/min, power, weight, and power/volume. The outputs range from 0.2 MW (270 hp) to 2.73 MW (3660 hp), and above that the author considers gas turbines to 4.81 MW (6450 hp). He discusses marine propellers, jet units, and air propellers as well as transmission schemes.

[20] Author(s): Devine, M.; Beyer, C.; Tsao, S.
Title: <u>ASSET: Advanced Surface Ship Evaluation Tool Manual</u>
Mag/Publ: Boeing Computer Services Date: 1983 Pages: 999
Category: General
Keywords: CAD Design ASSET
Abstract: Four binders worth of user and theory manuals for this synthesis tool meant for technology evaluation. The original ASSET is for hydrofoils. This particular ASSET version is for surface monohulls; another version is in prototype for SWATH hulls.

[21] Author(s): Dorman, W; Henry, J.
Title: "A Naval Architect and Ship Operator Spotlight Ways to Cut Building Costs"
Mag/Publ: Marine Eng. Log Date: 6/61 Pages: 4
Category: Preliminary Ship Layout
Keywords: Design Cost Cargo Ship
Abstract: The authors recommend adoption of a more frugal attitude to stem the general practice of overdesigning and overbuilding U.S.-flag ships. They discuss the factors: size, speed/powering, cargo handling, arrangements (they recommend machinery aft), crew size, stability/subdivision, safety features, and duplications. They suggest specific ways a U.S.-flag cargo liner cost could be reduced (per ship) by $500,000 to $1,000,000 (1961). They include an appendix list of potential areas for cost reductions.

[22] Author(s): Drewry, John T.
Title: "Cost Estimating - A Crucial Function of the Ship Acquisition Process"
Mag/Publ: Naval Eng. Journal Date: 4/76 Pages: 13
Category: Preliminary Ship Layout
Keywords: Design-to-Cost Cost Budget
Abstract: Discusses role of cost estimating ("basis for requirement derivation, concept selection and establishing cost constraint, subsystem optimization, configuration management, and contract terms"). Uncertainty exists in cost estimates due to (a) technical element (b) financial element (c) time element (yrs. in advance) (d) other business/political. Lists five reasons for naval ship cost uncertainties. Discusses key elements as (a) past experiences (b) present knowledge (c) future expectations (trends). Espouses communication between the technical designer and cost estimator. Recommends a Ship Program Cost Estimating organization.

Author(s):

[23] Author(s): Drewry, John; Jons, Otto
Title: "Modularity: Maximizing the Return on the Navy's Investment"
Mag/Publ: Naval Eng. Journal Date: 4/75 Pages: 17
Category: Preliminary Ship Layout
Keywords: Modularity Cost Modernization
Abstract: Discusses the need for cost-effective design, traces the new construction SCN budget for various ship types against time, proposes modularity as a partial solution, and defines different facets of modularity (palletization, containerization, prepackaging, integrated containerization, and construction modularity). The paper presents cost breakdowns for past modernizations/conversions. It states that change in modern warfare is inevitable, and that modularity is 'design for change', and thus is cost-effective.

[24] Author (s): Eames, Michael
Title: "Advances in Naval Architecture for Future Surface Warships"
Mag/publ: Trans RINA Date: 4/80 Pages: 26
Category: Fleet Concept
Keywords: Propulsion Structure Innovation
Abstract: This wide-reaching study is a summary of a 1978 NATO Defense Research Group study on New Technologies. It discusses in broad terms propulsion, seakeeping, stability and control, materials and structure, power plants, and speculative vehicle concepts. He concludes that the science of high speed ships is well ahead of its exploitation, and that significant gains in sea speed and ride quality are possible in most vehicle types. Extensive figures and discussion add value to the paper.

[25] Author(s): Edwards, Dikby
Title: "Unique 'Bow Dock' Saves Time and Money"
Mag/Publ: Marine Eng. Log Date: 5/69 Pages: 2
Category: Shipyard as Factory
Keywords: Sonar Launch Drydock
Abstract: The described Bow Dock of Bath Iron Works is a giant floating cofferdam suficient to enclose only the sonar prow area. Bath's length of ways and available water depth prohibited launching of DDG-2 class ships with sonar dome attached; the bow dock saves having to drydock (nearest being 100 nm away). The savings from the first seven ships Bow-docked paid for the entire capital expenditure for construction of the unit.

[26] Author(s): Frankel, E.
Title: "Aspects of Ship Fabrication Process Design"
Mag/Publ: SNAME (LS) Date: 2/20/68 Pages: 21
Category: Shipyard as Factory
Keywords: Process/planning Process
Abstract: Describes the planning and process of a ship fabrication facility, by means of functional and operational flow diagrams.

[27] Author(s): Friedman, Norman
Title: U.S. Aircraft Carriers: An Illustrated Design History
Mag/Publ: Naval Institute Press Date: 1983 Pages: 427
Category: History
Keywords: Design Aircraft Aircraft/carrier
Abstract: The author discusses U.S. carrier development beginning with Langley (CV-1) of 1922. Austere carriers for WWII production, aborted small carrier designs, and amphibious-assault carriers are discussed. Appendices on catapults, arresting gear, magazine loads, and carrier characteristics (often with hard to find hull form characteristics and detailed weight breakdowns) add to the value of this volume, companion to Mr. Friedman's destroyer and cruiser design histories.

[28] Author(s): Friedman, Norman
Title: U.S. Destroyers: An Illustrated Design History
Mag/Publ: Naval Institute Press Date: 1982 Pages 489
Category: History
Keywords: Destroyer Design
Abstract: The author discusses the reasoning behind U.S. destroyer designs from 1886-1982, including torpedo boat forebears and destroyer escorts. The book has clear drawings and numerous photos, and considers not only ships that were buil t, but also designs that never made it off the drawing board. This history of U.S. destroyer development is based on internal, formerly classified papers of the U.S. Navy.

[29] Author(s): Friedman, Norman
Title: U.S. Naval Weapons
Mag/Publ: Conway Maritime Press Date: 1983 Pages: 287
Category: History
Keywords: Sensors Weapons Combat/systems
Abstract: Contains the history of U.S. weapon systems from 1883 to 1982, and contains significant tabular data on each system. Also discusses many electronics systems that are allied to the weapons, and the history of the U.S. Naval tactical and strategic thought. Heavily illustrated with diagrams and photos.

[30] Author(s): Gale, Peter
Title: "Margins in Naval Surface Ship Design"
Mag/Publ: Naval Eng. Journal Date: 4/75 Pages:
Category: Preliminary Ship Layout
Keywords: Margins Frigate Carrier
Abstract: The reasons why margins are utilized in ship design are outlined, and a system of classification of margins is presented (Design and Construction vs. Future Growth; ship system level vs. subsystem level; performance characteristics vs. physical characteristics). Some features of a rational design and construction margin are discussed. Data is presented on the actual growth experienced in recent U.S. naval ship designs.

[31] Author(s): Gallahue, James
Title: "Combat Systems Test Factory Through Shipboard"
Mag/Publ: Naval Eng. Journal Date: 10/80 Pages: 10
Category: Shipyard as Factory
Keywords: Combat/System Specifications Testing
Abstract: This paper discusses the planning and implementation of combat system tests with emphasis being upon the integrated phase of test and primarily the lead ship of a class.

[32] Author(s): Garzke, W.; Kerr, G.
Title: "Major Factors in Frigate Design"
Mag/Publ: SNAME Date: 11/19/81 Pages: 24
Category: Preliminary Ship Layout
Keywords: FFG-7 Frigate Comparative/ship/design
Abstract: The major factors in frigate design are identified in this paper. The effects of these 'drivers' (propulsion plant, max speed, cruising speed and endurance, type and number of helos, choice of combat systems, level of manning, and habitability standards) are illustrated by using variants of the FFG-7.

[33] Author(s): Gates, P.; Rusling, S.
Title: "The Impact of Weapons Electronics on Surface Warfare Design"
Mag/Publ: Trans. RINA Date: 4/82 Pages: 15
Category: Preliminary Ship Layout
Keywords: Combat/system Modularity Cost
Abstract: This discussion of modern electronics developments discusses high and low impact weapon systems, elex layout, vulnerability and modernization. In particular, the MEKO 360 and Cellular Light Frigates examples of modularity are touched upon. Cost-effectiveness with single-vs. multi-role, short life ships, and initial selection of weapons sections is discussed.

[34] Author(s): Glaser, K.
Title: "Self-Locking Aluminum Panels Speed Construction Work"
Mag/Publ: Iron Age Date: 10/8/60 Pages: 2
Category: Production Details
Keywords: Deckhouse Aluminum
Abstract: Aluminum extrusions for deckhouse panels that snap-lock into place are described. A 17% weight savings (extruded over conventional aluminum), 22% material cost savings, and labor cost savings of 42%, for an estimated overall savings of 32%. It is claimed that stress concentrations are reduced. A polysulfide sealant is applied to the snap joint prior to snapping to ensure a weather-tight joint and to increase the shear strength of the joint.

[35] Author(s): Goddard, Charles H.
Title: "A Methodology for Technology Characterization and Evaluation for Naval Ships"
Mag/Publ: MIT Thesis,O.E. Date: 1985 Pages: -
Category: General
Keywords: Innovation Design ASSET
Abstract: The author discusses how to develop a baseline ship and evaluate new technologies for naval ships. Several case studies are performed, including one on NAVTRUSS and one on IRGT.

[36] Author(s): Gooch, F.W.
Title: "The Navy's Program for Shipyard Modernization"
Mag/Publ: SNAME (LS) Date: - Pages: 25
Category: Shipyard as Factory
Keywords: Cranes Handling
Abstract: This paper outlines the modernization program, concentrating on Philadelphia Naval Shipyard as the pilot in the program.

[37] Author(s): Graham; Nickelsburg
Title: "'Design to Cost'-A Viable Concept in Naval Ship Design"
Mag/Publ: Naval Eng. Journal Date: 4/76 Pages: 18
Category: Preliminary Ship Layout
Keywords: Design-to-Cost Cost Design
Abstract: FFG-7 (Perry) class is used as a case study to examine "Design to Cost" design philosophy. Mentions three ways to reduce cost (a) reduce performance (b) take advantage of technology (c) improve management to produce a tight design. A comparative design analysis of FFG-7 with regards to weight and volume allocation is performed. He gives a comparison of various ship and functional densities and specific ratios (tons/man, ft^3 /man, lbs/SHP, ft^3 /SHP) and traces FFG 7 design trade-off decisions, concluding that of the three ways to reduce cost, reducing performance dominates.

[38] Author(s): Graham, Clark
Title: "Factors Affecting Naval Ship Design"
Mag/Publ: Naval Eng. Journal Date: 2/72 Pages: 9
Category: Preliminary Ship Layout
Keywords: Design Combatant
Abstract: This paper discusses trends over time in U.S. naval combatant design, and focusses on complexity. The amount of design effort depends on 'efficiency of the design effort' and 'complexity of particular ship under design'. The author discusses organizational structure, business practices, frequency of design, and the effect of increased performance requirements.

[39] Author(s): Graham, Clark
Title: "The Impact of Subsystems on Naval Ship Design"
Mag/Publ: Naval Eng. Journal Date: 12/75 Pages: 9
Category: Preliminary Ship Layout
Keywords: Marginal/cost Design Impact
Abstract: Author submits that ship subsystems and components must be designed in a system environment if the Navy is to produce balanced, efficient naval ship designs. He desires that subsystem designers become aware of how their designs impact the overall ship system design, and that they be provided with the analytical tools to determine the "true cost" of subsystems. He explains Marginal Cost Factors as one such tool, and proposes devoting efforts to producing "low ship-impact subsystems".

[40] Author(s): Graham, C.; Howell, J.
Title: "Marginal Weight Factors for Surface Combatant Ships"
Mag/Publ: ASE Date: 3/76 Pages: 34
Category: Preliminary Ship Layout
Keywords: Design Weight Marginal/Cost
Abstract: The concept of utilizing marginal cost factors to determine the overall ship impact of design features is examined. The validity of the concept was confirmed through a comparison with weight impact predicted directly by synthesis model.

[41] Author(s): Gribskov, Jon; Storch, Richard
Title: "Accuracy Control for U.S. Shipyards"
Mag/Publ: Journ. Ship Prod. Date: 2/85 Pages: 14
Category: Shipyard as Factory
Keywords: Statistical
Abstract: Accuracy control is defined as the use of statistical techniques to monitor, control and continuously improve shipbuilding design details and work methods so as to maximize productivity. This paper discusses the steps necessary to initiate an accuracy control system. Case studies are based on Navy T-AGOS vessels at Tacoma Boatbuilding Company.

[42] Author(s): Guest, W.
Title: "Ingalls: Past, Present and Future"
Mag/Publ: SNAME (LS) Date: 5/3/68 Pages: 20
Category: Shipyard as Factory
Keywords: Ingalls Shipyard
Abstract: Discusses the history of Ingalls since WWII and its plans for shipbuilding technology innovation.

[43] Author(s): Hall, Jon; Anderson, Michael
Title: "The U.S. Coast Guard Multi-Mission Cutter: Command, Display, and Control (COMDAC)"
Mag/Publ: Naval Eng. Journal Date: 10/80 Pages: 11
Category: Preliminary Ship Layout
Keywords: Computer Software
Abstract: This paper by USCG officers describes the automated approach to employ the principles of a command, communication, and control system to achieve both a multimission posture and minimal manning in the replacement Medium Endurance Cutter.

[44] Author (s): Hawking, R.S.
Title: "Progress in Naval Machinery During the Last Thirty Years"
Mag/Publ: Naval Eng. Journal Date: 10/66 Pages: 8
Category: Production Details
Keywords: Propulsion
Abstract: The author, a Royal Navy Admiral, discusses steam, diesel, gas turbine, nuclear and combined plants, and summarizes the basis for selection and design of machinery installations.

[45] Author(s): Helming, James; Munger, Francis
Title: "Productivity in Shipbuilding"
Mag/Publ: Industrial Eng. Date: 1/79 Pages: 3
Category: Shipyard as Factory
Keywords: Standards
Abstract: Describes the National Shipbuilding Research Program and the subprogram managed by Bath Iron Wrok (Producibility). The first 5 years of effort were concentrated on improved ship design and shipyard operations from the standpoint of construction. In 1977, efforts were redirected towards industrial engineering and standards/specifications.

[46] Author(s): Hockberger, William A.
Title: "Ship Design Margins - Issues and Impacts"
Mag/Publ: Naval Eng. Journal Date: 4/76 Pages: 13
Category: Preliminary Ship Layout
Keywords: Standards Margins Cost
Abstract: Categories of Design and Construction Margins, Future Growth Margins, and Assurance Margins are discussed. The cascading effects of margins are demonstrated on an initially unmargined baseline destroyer. He discusses the feasibility of cost reduction by margin reduction. NAVSEA's DD07 design synthesis model was used for analysis.

[47] Author(s): Hovgaard, William
Title: General Design of Warships
Mag/Publ: Spon & Chamberlain, NY Date: 1920 Pages: 307
Category: General
Keywords: Combatant Design
Abstract: Follows his Modern History of Warships and precedes his Structural Design of Warships, based on lectures for Naval Construction course at Massachusetts Institute of Technology. Covers preliminary design; size of warships, elements of shape, preliminary weight calculations, subdivision, etc. Vintage text, useful for its insight and philosophy.

[48] Author(s): Hovgaard, William
Title: Modern History of Warships
Mag/Publ: Spon & Chamberlain, NY Date: 1920 Pages: 502
Category: History
Keywords: Combatant Design
Abstract: First of a series of three books based upon lectures prepared for the Naval Construction course at Massachusetts Institute of Technology. It is a historical review of armored warship design starting with Fulton the First (1813) but concentrating on the period 1895 to 1920. It covers all types including submarines and airships, and the final chapters cover technical aspects of hull, machinery, ordnance, mines/torpedoes, and protection. It is a vintage text, useful for early periods. See Friedman's books on design history for post World War I to mid 1980's.

[49] Author(s): Jeffrey, D.C.
Title: "Numerical Bending of Bulb Flats"
Mag/Publ: Marine Eng. Log Date: 1/77 Pages: 1
Category: Production Details
Keywords: Structure Frames
Abstract: Discusses European and Japanese use of bulb flats vice U.S. practice of converted rolled steel channels for transverse ship's frame angles. The bulb (or Holland type) frame, when used as the offset bulb variant, has the advantage that port and starboard frames can be placed back to back and bent cold in an hydralic frame bending machine. The author argues for a limited range of bulb flat sizes, and numerically controlled benders would have additional utility.

[50] Author(s): Johnson, Richard
Title: "The Cost of Finishes and Tolerances"
Mag/Publ: Naval Eng. Journal Date: 11/58 Pages: 6
Category: Production Details
Keywords: Standards Cost
Abstract: Contains interesting quote from 'Modern Arms and Free Men' by Dr. Vannevar Bush: "There is a common notion that during war costs do not count. There is no greater fallacy." He provides examples of over-specifications regards finishes, and provides cost data for various finishes/roughness.

[51] Author(s): Johnson, Robert
Title: "Naval Ship Design: The Shipbuilders' Emerging New Role"
Mag/Publ: Naval Eng. Journal Date: 5/85 Pages: 12
Category: General
Keywords: Design DDG-51 MSH
Abstract: Private shipbuilders are assuming an expanded role in the ship design process beyond their traditional involvement in detail design and the construction phase. The two design approaches for recent U.S. Navy designs (DDG-51 and Minesweeper Hunter (MSH)) are discussed. The cost saving measures and producibility studies of DDG-51 are highlighted, and the short-comings of this first producibility design effort are pointed out.

[52] Author(s): Johnston, William; Nichols, Robert
Title: "State of the Art of Shipboard Drives - Past,Present,Future"
Mag/Publ: SNAME (LS) Date: - Pages: 36
Category: Preliminary Ship Layout
Keywords: Propulsion Electric
Abstract: This paper traces how A-C drives came to be the standard for most marine installations.

[53] Author(s): Jolliff, James V.
Title: "The 400 Hertz Dilemma"
Mag/Publ: Naval Eng. Journal Date: 10/81 Pages: 10
Category: Preliminary Ship Layout
Keywords: Motorgenerator Power Impact
Abstract: The paper discusses the history which led the U.S. Navy into having both 60 hz and 400 hz M-G set, discusses current problems with 400 hz and current initiatives to minimize or eliminate 400 hz. He also discusses 400 hz as a case study of subsystem optimization rather than whole ship system optimization. Weight data is given.

[54] Author(s): Kay, C.H.
Title: "Trade-off Study: Single Wire vs. Two Wire Electrical Distribution System for SEV"
Mag/Publ: U.S. Navy Date: 8/71 Pages: 14
Category: Preliminary Ship Layout
Keywords: Electrical Wire JEFF B
Abstract: A study by Bell Aerospace Co. for the JEFF B Surface Effect Vehicle (SEV). It concludes that the single wire distribution system should be reimplemented on the landing craft, due to: lighter weight (at least 340 lbs); easier implementation of protection from EM radiation; effective ground planes available for comm systems with proven results; less susceptability to RFI; and more economical.

[55] Author(s): Kehoe; Graham; Brower; Meier
Title: "Comparative Naval Architecture Analysis of NATO and Soviet Frigates"
Mag/Publ: Naval Eng. Journal Date: 10/80 Pages: 23
Category: Preliminary Ship Layout
Keywords: Comparative/ship/design Design Frigate
Abstract: This paper is a report of a comparative naval architecture analysis of U.S., Canadian, French, Netherlands, German, British, and Soviet frigates. It is published in two parts; part I in October covers arrangements, weapons, survivability, stability, and manning, while part II in December covers hull form, propulsion, speed, range, seakeeping, size, and future growth. They conclude that a 'Sovietized' FFG-7 would have 75% of full-load displacement of the original design.

[56] Author(s): Kehoe, James
Title: "Warship Design - Ours and Theirs"
Mag/Publ: Naval Eng. Journal   Date: 2/76   Pages: 9
Category: Fleet Concept
Keywords: Standards Design Comparative/ship/design
Abstract: A discussion of why Soviet surface combatants appear to be smaller, faster, and yet more heavily armed than the U.S. counterparts. Size, speed, habitability, specific payload volume, and armament trends are discussed for both navies. The answer of why is: Soviet use of 'low impact' weapons with few or no reloads; Soviet low specific volume power plants (crowded); modest payload performance of Soviet designs; and more modest Soviet design standards (particularly for habitability and growth). A 'sovietized' FF-1052 design is examined as a case study.

[57] Author(s): Kurfehs, George
Title: "The Cost of Ships - USA vs. Foreign"
Mag/Publ: Marine Eng. Log   Date: 4/60   Pages: 3
Category: Preliminary Ship Layout
Keywords: Cost Merchant
Abstract: This paper deals with the cost of building commercial ships and examines why U.S. ships are comparatively expensive. He concludes that U.S. ships are about twice as expensive because: (1) wages, (2) overhead, and (3) difference in standards.

[58] Author(s): Lafferty, James
Title: "Special Trucks Do Their Thing: Navy's Drydock Costs Tumble"
Mag/Publ: Material Handling Eng.Date: 4/70   Pages: 3
Category: Shipyard as Factory
Keywords: Shafting Rigging
Abstract: This article describes a precision rigging system of two platform trucks designed to offer versatility and savings in handling ships' rudders, propellers, and shafting. It was devised for Long Beach Naval Shipyard for drydock repair of naval ships.

[59] Author(s): Lane, Frederic C.
Title: Ships for Victory - A History of Shipbuilding Under U.S. Maritime Commission in World War II
Mag/Publ: John Hopkins Press   Date: 1951   Pages: 900+
Category: Wartime Producibility
Keywords: Mobilization Shipbuilding Design
Abstract: A history of shipbuilding under the U.S. Maritime Commission in World War II. It examines the combination of government regulation and private enterprise that characterized WWII naval and merchant mobilization efforts. It discusses the ship design and mods for Liberty (merchant) ships, and discusses programmatic issues for both merchant and naval types.

[60] Author(s): Lankford, Benjamin
Title: "A Comparison of Naval and Commercial Standards for. . . .Hull Structure"
Mag/Publ: Naval Eng. Journal Date: 2/68 Pages: 7
Category: Fleet Concept
Keywords: Standards Structure Cost
Abstract: The author discusses the "weight costs money" concept and then compares the design methods (Navy and Commercial). He concludes that shipbuilder's preference/experience is crucial, as is the framing system (longitudinal for Navy), and that the trend in decision making is to compare Life Cycle Costs.

[61] Author(s): Levedahl, William
Title: "Integrated Ship Machinery Systems Which Result in Small, Efficient Destroyers"
Mag/Publ: Naval Eng. Journal Date: 4/80 Pages: 8
Category: Preliminary Ship Layout
Keywords: Propulsion Design
Abstract: The author states that integrated ship machinery systems can sharply reduce destroyer size, installed power, and fuel consumption. He suggests aircraft derivative gas turbines, electric transmission, battery energy storage, and contrarotating propellers. Studies with DD07 in a 'rubber ship' mode suggested synergisms, and he concludes with estimates that a Spruance class baseline could save 3000 tons off full load displacement with an integrated machinery system.

[62] Author(s): Lisanby; Haas
Title: "Use of Commercial Specifications in the Shipbuilding Process"
Mag/Publ: Naval Eng. Journal Date: 2/81 Pages: 8
Category: Preliminary Ship Layout
Keywords: Specifications Standards Design
Abstract: Discusses documents referenced in the acquisition of ships by the Navy, and some alternatives for simplification; maximum use of industry standards, use of Commercial Item Descriptions, and use of military documents where necessary.

[63] Author(s): Litman, N.
Title: "DDG-51 Special Study No. 43: Determine Ship Impact of Lightweight Reduction Gear"
Mag/Publ: U.S. Navy Date: 1/28/83 Pages: 14
Category: Preliminary Ship Layout
Keywords: DDG-51 Gear Reduction
Abstract: This study by Gibbs and Cox, Inc. can be found in the Surface Combatant Data Bank of NAVSEA 503. They check ship impact of replacing baseline gear (effective K=133) with a maximum achievable through-hardened gear (effective K-185), and conclude that 100 LT of displacement can be saved. They also considered surface hardened and ground gears, and estimate significant increases in ship radiated noise. They recommend simple elimination of gear reaction mass (as in FFG7 vice DD963).

[64] Author(s): Livesey, Roger
Title: "Big Ships, Mass-Produced"
Mag/Publ: Engineering Date: 5/2/69 Pages: 1
Category: Shipyard as Factory
Keywords: Tankers Series/production Welding
Abstract: Briefly describes the processes in the new highly mechanized flat section shop and a new assembly shop at Gotaverken's Arendal Shipyard in Sweden. Single-sided welding is utilized, and the 227,000 ton tankers under order are twice the size of vessels previously built at Arendal.

[65] Author(s): McEntee, William
Title: "Cargo Ship Lines of Simple Form"
Mag/Publ: SNAME Trans #25 Date: 1917 Pages: -
Category: Preliminary Ship Layout
Keywords: Resistance Hull
Abstract: An early discussion by a naval constructor in the U.S. Navy. Also of interest is an extended discussion by Professor Herbert Sadler of the University of Michigan who describes a straight-lined hull form for a cargo ship, and provides a drawing of the lines.

[66] Author(s): McGarrity, William
Title: "Stronger Materials Cut Operating Costs, Increase Payloads"
Mag/Publ: Metal Progress Date: 2/68 Pages: 4
Category: Preliminary Ship Layout
Keywords: Steel
Abstract: Discusses the impact of higher strength steels on the transportation industry: trucks, railroad cars, and ships.

[67] Author(s): McIntire, John; Holland, George
Title: "Design of the AO 177 Machinery Plant"
Mag/Publ: Naval Eng. Journal   Date: 2/76   Pages: 12
Category: Production Details
Keywords: Propulsion Steam Control
Abstract: The AO 177 (U.S. Navy fleet oiler) is a cost constrained design for a ship with minimum manning. The machinery plant was designed for simplicity, low maintenance, and a high degree of centralized control and monitoring. This paper describes the 24,000 SHP single screw steam plant with emphasis on the machinery plant central control system design.

[68] Author(s): Mealy, Michael
Title: "Japanese Shipyards Thrive on Automation"
Mag/Publ: American Machinist   Date: 5/27/74 Pages:6
Category: Shipyard as Factory
Keywords: Shipyard Automation Modularity
Abstract: Discusses Japanese shipyard automation with examples from four yards (Mitsui's Chiba, Mitsubishi's Koyagi, IHI's Chita, and Nippon Kokan's Tsu). Themes presented are modular assembly, heavy movement, pipe processing, numerical control, and computers. Photos and diagrams are included.

[69] Author(s): Montgomery, F.; Siegal, I.
Title: "Increased Productivity in the Construction of Liberty Vessels"
Mag/Publ: Monthly Labor Review Date: 11/43 Pages: 4
Category: Wartime Producibility
Keywords: Liberty Series
Abstract: This is an early source of data on the Liberty ship building program, and contains statistics of unit man-hour requirements and time requirements for Liberty vessels delivered Dec. 1941 to April 1943, with a further comparison between five yards of the effects of series production. The authors state that standardization and mass production explain the observed reduction to great extent, but cite other reasons.

[70] Author(s): Mooney, James L.
Title: <u>Dictionary of American Naval Fighting Ships</u>
Mag/Publ: Naval Historical Center Date: 1981 Pages: 999+
Category: History
Keywords: Warship Austere
Abstract: As the title indicates, an alphabetical listing of warships with a historical article on each. Of particular interest are Appendix I about Patrol Craft and Sub-chasers, and Appendix II about the Ford-built Eagle-class Patrol Craft (PE) of WWI.

[71] Author(s): Morison, Samuel Eliot
Title: The Two-Ocean War
Mag/Publ: Ballantine Books Date: 1963 Pages: 534
Category: General
Keywords: WWII
Abstract: A paperbook, condensed version of the author's 15 volume History of U.S. Naval Operations in World War II.

[72] Author(s): Nappi; Walz; Wiernicki
Title: "The 'No Frame' Concept - Its Impact on Shipyard Cost"
Mag/Publ: Naval Eng. Journal Date: 5/84 Pages: 16
Category: Preliminary Ship Layout
Keywords: Structure Framing Hull
Abstract: This proposed cost effective alternative to current U.S. Navy structurally configured hulls involves elimination of structural stanchions and transverse web frames. It promises (1) reduced cost for distributed system installation, and (2) a reduced number/complexity of structural details for more reliability and less cost. Studies on FFG-7 and DD-963 indicate 7% heavier and 15% less costly structural weights. Accounting for reduced distributed system work, and FFG-7 was estimated possible with 7% fewer man hours. Concerns are expressed for openings in 'no frame' deck and vibrational response. Transverse bulkhead must be 24' apart vice 40' apart 'as built'.

[73] Author(s): NAVSEA report
Title: Ship Design Project Histories
Mag/Publ: U.S. Navy Date: 9/30/79 Pages: 200
Category: General
Keywords: Schedule Cost Manhours
Abstract: This publication is a quick reference comparative summary and planning guide for ship design programs. It is for internal NAVSEA use only. It contains escalation tables for 1971-1979 and design summaries of all designs of that period, with description of ship and program, constraints, special factors, key personnel, design elements, and references. Costs, manhours, and schedule are compared in figures.

[74] Author(s): Niedermair, John
Title: "As I Recall. . .Designing the LST"
Mag/Publ: Proceedings Date: 11/82 Pages: 2
Category: Preliminary Ship Layout
Keywords: Requirements LST Design
Abstract: Taken from an oral history interview conducted 9 December 1975 with the designer, the civilian technical director of the Preliminary Design Branch of the Design Division of the U.S. Bureau of Ships. Provides an account of the 300' LST design to British requirements to land the biggest tanks. The initial scheme was sketched in November 1941, and never changed much. The first LST was finished in October 1942.

[75] Author(s): Piel, Gerard
Title: "No. 1 Shipbuilder"
Mag/Publ: Life Date: 6/29/42 Pages: 8
Category: Wartime Producibility
Keywords: Kaiser Series/production
Abstract: Discusses Henry Kaiser's first shipbuilding interest as all all-aluminum destroyer in 1939, and his effect as the pacesetter of the wartime shipbuilding program despite his lack of previous experience in shipbuilding.

[76] Author(s): Piersall; Borgstrom
Title: "Cost Analysis of Optional Methods of Shipboard Domestic Waste Disposal"
Mag/Publ: Naval Eng. Journal Date: 2/73 Pages 7
Category: Production Details
Keywords: Sewage Cost CHT
Abstract: Discusses four major options for sewage and waste disposal on non-nuclear, sea going surface ships with manning above 50. The options are: Onboard treatment (sanitation devices) with backup holding capacity; Onboard holding tanks with direct discharge ashore for treatment; Onboard holding tanks with treatment aboard barges; and Onboard holding tanks with treatment ashore, barges to collect and transfer. Option B is judged least costly.

[77] Author(s): Rains, Dean
Title: "Design Synthesis, Effectiveness, and Cost Model"
Mag/Publ: unpublished Date: - Pages: -
Category: General
Keywords: Cost Effectiveness Computer
Abstract: Mr. Rains of Decision Engineering, 3012 Northwood Road, Pascagoula, MS 39567 has implemented design, effectiveness, and cost models on Apple and IBM micro-computers. Most interesting are the effectiveness models which are for Group Defense, Strike Warfare, Passive Survivability, IR Signature, Visual Signature, Underwater Radiated Noise, and ASW warfare.

[78] Author(s): Ramsay, Raymond
Title: "Approaches to Improving Shipbuilding Producibility"
Mag/Publ: ASE Date: 3/83 Pages: 38
Category: Fleet Concept
Keywords: Shipyards Subsidy
Abstract: The author recommends a wide range of remedies for the poor state of the U.S. shipbuilding industry, including: centralized long-term planning as a national industry, subsidy, attractive financing, interrelation of shipyard and support-industry operational structures, product innovation, and workforce training. Some cost data is presented comparing U.S. with other shipyards, showing U.S. flag merchant fleet trends, and plotting the active U.S. shipbuilding base.

[79] Author(s): Ramsay, Raymond
Title: "Improving the National Shipbuilding Industrial Base"
Mag/Publ: 19th Tech Symp, ASE Date: 1982 Pages 47
Category: Shipyard as Factory
Keywords: Shipyards Shipbuilding
Abstract: Provides a small shipbuilding history, a U.S. Shipbuilding Status brief, discusses the decline in productivity and the shipbuilding workforce, discusses management lessons from Japan, and concludes that U.S. government 'partnership' with public and private shipyards is necessary to reverse alarming trends of workload projections and layoff of shipyard workers. The last 17 pages are many good charts and figures, including last figure of 'active U.S. shipbuilding base'.

[80] Author(s): Ramsay, Raymond
Title: "New Directions for Navy Manufacturing and Shipbuilding Technology"
Mag/Publ: SNAME Date: 4/6/83 Pages: 13
Category: Fleet Concept
Keywords: Innovation Subsidy
Abstract: This paper, presented at the Spring Meeting/-STAR Symposium, postulates that technological 'widgets and gadgets' have less impact on productivity than design/planning/production process integration and standardized production procedures. The author recommends legislative relief to restore merchant shipbuilding to the U.S. as a national asset. He also discusses the Navy's Five Year Plan ('83-'87) and discusses the available capacity of American shipyards.

[81] Author(s): Ramsay, Raymond
Title: "A Time for Shipbuilding Renaissance"
Mag/Publ: Naval Eng. Journal Date: 9/83 Pages: 30
Category: Fleet Concept
Keywords: Shipyard Subsidy
Abstract: This paper provides an overview of the U.S. shipbuilding and repair industry and its capabilities, and workforce management practices in foreign countries are discussed.

[82] Author(s): Rawson, K.;Tupper, E.
Title: Basic Ship Theory, Vol. I and II
Mag/Publ: Longman, London Date: 1968 Pages: 701
Category: General
Keywords: Design
Abstract: An excellent text in fundamental naval architecture.

[83] Author(s): Rein; Ryan
Title: "Technological Advances in Aircraft Carrier Design"
Mag/Publ: Naval Eng. Journal Date: 10/80 Pages: 15
Category: Preliminary Ship Layout
Keywords: Aircraft/carrier Design Computer
Abstract: The authors discuss computer design applications and the CV02 synthesis model. Also, the impact of V/STOL aircraft on aircraft carrier design is discussed, as was advanced structural design; the use of low sills in openings through Bent frames on the Gallery deck; use of shallow aircraft elevator platforms; and limited access through the sheer strake to the sponsons. A description of a total ship energy conservation analysis was also done.

[84] Author(s): Rodgers, William L.
Title: Naval Warfare Under Oars -4th to 16th Centuries
Mag/Publ: Naval Institute Press Date: 1941 Pages: 358
Category: History
Keywords: Warship Tactics Design
Abstract: A classic in the history of naval warfare, this is a study of fleet naval tactics in the days of rowing ships of the Christian era. It also gives brief sketches of the underlying political and economic conditions, and contains lucid appendices on topics of ship design of the time.

[85] Author(s): Roper, J.L.
Title: "Planned Retooling Cuts Shipyard Costs"
Mag/Publ: Marine Eng. Log Date: 9/62 Pages: 2
Category: Shipyard as Factory
Keywords: Air/tools Tools Caulking
Abstract: The author, VP of Norfolk Shipbuilding, states that "shipbuilding is perhaps the most job-shop oriented segment of industry." He cites the importance of tool maintenance in cost reduction. An example is cited of converting from hand-caulking to use of air caulking hammers. He further describes how to compute savings from tool replacement.

[86] Author(s): Rowley, U.H.
Title: "Methodology for Computer-Supported Comparative Naval Ship Design"
Mag/Publ: MIT Thesis,O.E. & M.E. Date: 1985 Pages: -
Category: General
Keywords: Comparative/ship/design ASSET DDG-51
Abstract: The author details how to implement a comparative naval ship design module within the Advanced Surface Ship Evaluation Tool (ASSET) synthesis model. A comparison of DD-963 and DDG-51 is conducted to validate the methodology and screens are designed for future programming/implementation. Classified supplement.

[87] Author(s): Shapley, Deborah
Title: "Addiction to Technology is One Cause of Navy's Shipbuilding Crisis"
Mag/Publ: Science Date: 5/19/78 Pages: 5
Category: Fleet Concept
Keywords: Series/production Cost Schedule
Abstract: This article discusses shipbuilder claims against the Navy, the Navy's method of procurement, and political considerations.

[88] Author(s): SNAME Ship Production Committee
Title: The Five-Year National Shipbuilding Productivity Improvement Plan (1983-1988)
Mag/Publ: SNAME Date: 1983 Pages: 107
Category: General
Keywords: Research
Abstract: Consists of two parts. The first consists of the basic plan which set forth overall goals, a research strategy, and provide for development of a management system plus timetable for carrying out admin details of this strategy. The second part (Appendix A) is a compilation of research projects completed, in progress, and proposed for fiscal year 1984. Task groups include Engineering, Manufacturing, Technology, Material Management, Material Handling, Quality Assurance, Human Resources, Business Environment, and Welding.

[89] Author(s): Stumbo, Stanley
Title: "Impact of Zone Outfitting on Ship Space Utilization and Construction Costs"
Mag/Publ: Naval Eng. Journal Date: 5/85 Pages: 9
Category: Shipyard as Factory
Keywords: Zone/outfit Margins SSDG
Abstract: This paper describes a 3-D approach to the use of enclosed volume through the use of zone outfitting vice conventional system oriented methods. Zone oriented methods can lead to new warship design margins, as well as provide up to 30% savings in construction costs. A case study of SSDG's on the LSD-41 class illustrates that it were to be redesigned by zone-oriented methods, the spaces would be smaller, have a higher specific machinery volume, and still contain the same systems and components at the same equipment densities.

[90] Author(s): Swain; Poyer
Title: "Application of Fiber Optic Technology to Shipboard Use: Near and Far-Term"
Mag/Publ: Naval Eng. Journal Date: 7/84 Pages: 6
Category: Preliminary Ship Layout
Keywords: Fiber/optics Cables Data
Abstract: Fiber optics (pulses of light, conducted through channels of glass) offer advantages of lighter weight, easier running, cheaper installation, and shock resistance over conventional multi-wire systems. It's proven in commercial use, and approaching its first operational shipboard application. This brief overview of fiber optics discusses principles of operation, standarization, and planned installation procedures.

[91] Author(s): Tanaka, Hisashi
Title: "Modern Production Methods for Large Ships"
Mag/Publ: Proc. IEEE Date: 4/68 Pages: 8
Category: Shipyard as Factory
Keywords: Computer Design
Abstract: The author, who is with Mitsubushi Heavy Industries, Ltd., outlines the shipbuilding industry and ship design, then concentrates on computer applications in shipbuilding for structural calculations, mold lofting and cutting, computerizing the working drawing, and production control.

[92] Author(s): Vaughn; Langston; Wapner; Fastring
Title: "Comments on "Current Trends in Naval Data Handling Systems""
Mag/Publ: Naval Eng. Journal Date: 7/84 Pages: 3
Category: Preliminary Ship Layout
Keywords: Computers Data Cables
Abstract: The first two authors provide comments on the paper by the second two, and Wapner and Fastring respond. They discuss flexible data management and distributed processing. DDG-51 will transfer combat system data over low level cables vice the 90 wire parallel cables used in prior ships, for weight savings and survivability. SDMS is the first of these distributed systems.

[93] Author(s): Wakefield, B.
Title: "The One-a-Day Barge Builder"
Mag/Publ: Iron Age Date: 4/24/69 Pages: 3
Category: Shipyard as Factory
Keywords: Series/production Alternate/shipyards
Abstract: Jeffboat, Inc. is one of the largest inland shipyards, and is number one in annual barge construction. Located on the Ohio River, it has implemented Avondale and automotive techniques. Units weigh up to 350 tons, and a barge is launched every four days. The barge production line has 4 positions, with movement accomplished just prior to the morning shift to minimize disruption. The barges sometimes measure as large as 300 feet by 60 feet.

[94] Author(s): Walsh, Sean P.
Title: "An Improved Method for Risk Analysis for Naval Ship Design Process"
Mag/Publ: MIT Thesis, O.E. Date: 1985 Pages: -
Category: General
Keywords: Design Risk
Abstract: This thesis pursues a more quantitative method of categorizing and analyzing risk involved in naval ship design.

[95] Author(s): Weiers, Bruce
Title: "The Productivity Problem in U.S. Shipbuilding"
Mag/Publ: Journ. Ship Prod. Date: 2/85 Pages: 22
Category: Shipyard as Factory
Keywords: Group/technology Zone/outfit Automation
Abstract: This important article is the best single source of information on modern shipbuilding methods and producibility. Mr. Weiers discusses all aspects of the problem and the solution. His list of references is a valuable resource.

[96] Author(s): Williams, Don
Title: "Fiber Optics Technology and Systems in the Navy"
Mag/Publ: Naval Eng. Journal Date: 4/75 Pages: 9
Category: Preliminary Ship Layout
Keywords: Cable Fiber/optic Data
Abstract: Fiber optics has become a candidate to replace metallic wire conductors. This paper summarizes the technology.

[97] Author(s): Wilson; Foltis
Title: "Concept Study of Mobilization Tug-Barge Designs"
Mag/Publ: Naval Eng. Journal   Date: 4/80   Pages: 11
Category: Wartime Producibility
Keywords: Mobilization Merchant
Abstract: This paper discusses current U.S. capability to construct the jumbo version of the Maritime Administration's multi-purpose, mobilization ship preliminary design, and the need for other designs suitable for construction in smaller shipways and alternate yards. Four conceptual designs for tug-barge combinations are presented.

[98] Author(s): -
Title: "Annual Report on the Status of the Shipbuilding and Ship Repair Industry of the U.S."
Mag/Publ: U.S. Navy   Date: 1982   Pages: -
Category: Economic Considerations
Keywords: Shipyards Workload
Abstract: This report provides an overview of the major shipbuilding programs, ship conversions, and modernizations, shipyard improvements, and research and development programs. Worldwide shipbuilding is on the decline, with only Japan, South Korea, Denmark, Norway and Finland in relatively good market position. U.S. industry employment decreased from 252k in 1981 to 238k in 1982.

[99] Author(s): Editor
Title: At Avondale: Productivity Up and Costs Down
Mag/Publ: Marine Eng. Log   Date: 11/76   Pages: 3
Category: Shipyard as Factory
Keywords: Welding
Abstract: Avondale Shipyards recently installed an automated welding system to produce T, L, and angular beams. The total cost of the system was over $750,000, but Avondale expects the system to pay for itself within three or four years.

[100] Author(s): Editor
Title: "Cutting Coating Costs for New Ships and Old"
Mag/Publ: Marine Eng. Log Date: 8/74 Pages: 3
Category: Production Details
Keywords: Paint Hull Corrosion
Abstract: Discusses recent advances in hull coatings that can significantly reduce the need to repaint. Merchant vessels have used this to enable crew reductions and extend the life of older ships. The coatings have impact on design as well (particularly small steel vessels) as corrosion allowances may be reduced.

[101] Author(s): Editor
Title: "How Much Do Marine Coatings Really Cost?"
Mag/Publ: Marine Eng. Log Date: 11/71 Pages:5
Category: Production Details
Keywords: Protection Paint
Abstract: Discussion of paint for ships. Author states that true cost equals applied cost plus maintenance costs plus cost of ship's nonavailability, all divided by the effective service life of the coating system. Glass-flake, zinc-rich, chlorinated rubber, vinyl resin, and epoxy paints are discussed generally.

[102] Author(s): Editor
Title: "How the Shipyards are Speeding Up to Challenge the U-Boats"
Mag/Publ: Current Opinion Date: 9/17 Pages: 2
Category: Wartime Producibility
Keywords: Austere Shipping Cargo
Abstract: A historical tid-bit that describes WWI cargo ship production, briefly discusses the economics of submarine anti-shipping warfare, but most interestingly discusses the Eustis-Clark plan. This plan was for 3,000 ton wooden ships vice 30,000 ton steel ships to be constructed to provide trans-Atlantic shipping.

[103] Author(s): Editor
Title: "Keel to Commission: 14 Days"
Mag/Publ: Time Date: 10/5/42 Pages: 2
Category: History
Keywords: Kaiser Competition Series/production
Abstract: The _Joseph N. Teal_, 75th Liberty ship from Edgar Kaiser's Oregon Shipbuilding Co. was 'stunt' delivered (keel to delivery) in 14 days, on the anniversary of the first _Liberty_ launching. Prefabrication is extensive, and the ship went down the ways 87% complete with steam in its boilers. Kaiser intra-organizational rivalry is also illustrated.

[105] Author(s): Editor
Title: "Machinery Layout Saves Steps and Dollars"
Mag/Publ: Marine Eng. Log Date: 9/64 Pages: 4
Category: Preliminary Ship Layout
Keywords: Engine/room Steam Arrangement
Abstract: Describes the advance design Combustion Engineering top fired boilers and centralization of monitoring/control in SS Mormacargo's engineroom. Of note: FO settling tanks are located well aft (Hold 6) to utilize relatively useless space and permit reduction in the fore and aft length of the engine room. A single engineer at central console controls the 19,000 SHP main plant. Diagrams and photos are included.

[106] Author(s): Editor
Title: "Mechanized Welding Revives Shipyard Productivity"
Mag/Publ: Welding Journal Date: 1/82 Pages: 3
Category: Shipyard as Factory
Keywords: Alternate/shipyards Welding
Abstract: By replacing traditional manual welding with mechanized self-shielded flux-cored and submerged arc welding processes, Bay Shipbuilding of Sturgeon Bay, Wisconsin has increased productivity and improved weld quality. Photos accompany, and additional information is given of the yard's capability: it has built six 1000 foot long ships, and many ships in the 600-800 foot range. Sections can be up to 200 tons and 128 feet long.

[106] Author(s): -
Title: "National Shipbuilding Research Program Bibliography of Publications and Microfiche Index 1973-1983"
Mag/Publ: SNAME Date: 8/84 Pages: 52
Category: General
Keywords: References NSRP SPC
Abstract: Managed by the University of Michigan for the NSRP, this index lists (by SNAME Ship Production Committee panel) NSRP publications with an abstract. Barham [3] lists the entire index and how to obtain at nominal charge. Panel SP-4 (Design/Production Integration) has only two references, while SP-6 (Shipbuilding Standards) and SP-2 (Outfitting and Production Aids) have over twenty reports listed for each. The NSRP index and this bibliography can serve as adjuncts for a producibility research effort. The MIT Ocean Engineering 13A vault holds a copy of the index and the microfiche.

[107] Author(s): Editor
Title: "NKK Tsu Yard Features World's First 'Canalock' Building Dock"
Mag/Publ: Marine Eng. Log Date: 3/70 Pages: 4
Category: Shipyard as Factory
Keywords: Shipyard Mobilization
Abstract: Describes a new Korean shipyard and its state-of-the-art layout. The 'Canalock' is a drydock with sills on either end. Receipt of material, material flow, hull ship, production lines, transporting blocks, cranes, and the docks are all discussed. The maximum size for prefab blocks will be about 360 tons, based upon the combined capability of two 200 ton goliath cranes. NKK is Nippon Kokan, and construction capacity is to be six 150k dwt tankers per year with the 2175 year total employment.

[108] Author (s): Editor
Title: "Patrol Boats are Built Upside Down to Give Navy New One Each Week"
Mag/Publ: Popular Science Date: 6/42 Pages: 1
Category: Wartime Producibility
Keywords: Welding
Abstract: The use of rocker cradles to permit downhand welding. Mainly of interest to show popular interest in wartime production, and as a precurser to Avondale's use of the procedure on larger DE hulls 25 years later.

[109] Author(s): Editor
Title: "Prefabricated Deckhouses Give Highest Standards at Lower Cost"
Mag/Publ: Marine Eng. Log Date: 3/72 Pages: 2
Category: Production Details
Keywords: Deckhouse Prefab
Abstract: This Blohm and Voss patented prefabrication technique allows assembly of deckhouse (merchant oriented) in a building hall before the house is installed on the main deck. The advantages are: lower labor costs, high fire safety, quiet rooms, less maintenance.

[110] Author(s): Editor
Title: "Rotating Hull Speeds Ship Assembly"
Mag/Publ: Iron Age Date: 12/12/68 Pages: 1
Category: Shipyard as Factory
Keywords: Welding Hull
Abstract: Huge turning mechanisms (four rings) were designed and built by Avondale Shipyards for Destroyer Escort hulls. This permits maximum downhand welding. Each ring is equipped with a 125 ton capacity hydralic ram, and the entire ship can be rotated 180 degrees in 3 hours. After rotation to the upright position, prefabricated bow and stern sections and the majority of the machinery are installed.

[111] Author(s): Editor
Title: "Shave Installation Costs Via Use of Molded Insulation"
Mag/Publ: Marine Eng. Log Date: 10/64 Pages: 2
Category: Production Details
Keywords: Insulation
Abstract: Electric Boat asked Fibrous Glass Products to develop and produce a molded insulation for circumferential T beams of a submarine. The first full installation was on Tulibee in 1962. Installation time, cost effectiveness, and appearance all improved over the old Navy hull board method. Cost savings are estimated at 50%, with labor cost only 10% of old method due to reduced fitting and sealing. Costs in $ per linear foot are given for both methods.

[112] Author(s): Editor
Title: "Shipbuilder Hikes Production with Portable Welding Unit"
Mag/Publ: Welding Journal Date: 6/82 Pages: 2
Category: Production Details
Keywords: Welding Submerged Arc
Abstract: The article describes the portable unit selected by Todd Seattle Shipyard, its flexibility, quality, and cost advantages.

[113] Author(s): -
Title: Shipyard Mobilization Base Study
Mag/Publ: U.S. Navy Date: 2/84 Pages: -
Category: Fleet Concept
Keywords: Wartime Mobilization Shipyard
Abstract: This study assessed U.S. shipbuilding and ship repair capability, defined the probable demand for this capability, and measured the demand against the capability. Within the scenario studied, the first six months of demand could be met by industry, and overall peak demand occurs one and a half years into the war and requires a 75% increase over the D-day requirement. The study notes the trend of declining shipyard resources.

[114] Author(s): Editor
Title: "Simplified Fastener Sharply Reduces Cost of Cable Installation"
Mag/Publ: Marine Eng. Log Date: 3/64 Pages: 2
Category: Production Details
Keywords: Electrical Cable Hanger
Abstract: The Nelson Cable Hanger is described, a single piece consisting of a flux-filled stud and a cable hanger clip. The unit is end-welded to beams and bulkheads with a semi-automatic stud welding gun, and the cable is secured by bending clip legs with channel-lock pliers. New savings of 15 to 20 cents (1964) for each hanger are reported, or up to 50% in labor costs. The cable hanger is also easier to clean and paint.

[115] Author(s): Editor
Title: "Single Boiler Concept: 'High Satisfactory'"
Mag/Publ: Marine Eng. Log Date: 5/66 Pages: 3
Category: Preliminary Ship Layout
Keywords: Steam Boiler
Abstract: Letting one boiler do the work of two is now becoming standard practice in the design of new American merchant steamships. The advantages are simplicity, ease of automation, and lower initial cost. This is a summary of 4 papers given on the subject at the 14th Annual Fort Schuyler Forum. One paper described American President Lines' "Seamaster": 23 knot, 12 passenger freighters with one 870 psig boiler for 24,000 shp. In the unlikely event of a boiler failure at sea, the ship can make 8 knots with a 750 hp motor driving a reduction gear pinion.

[116] Author(s): -
Title: Surface Combatant Data Bank (NAVSEA 503)
Mag/Publ: U.S. Navy Date: Pages: 999
Category: General
Keywords: Design DDG-51
Abstract: This data bank is a valuable source for recent producibility data. The DDG51 design project funded studies by various shipyards that addressed tightness, minimum deckheights, modularity, armored trunk distribution, SDMS, metric standards, preoutfit, use of hull flare, HSLA, NAVTRUSS, and GRP piping producibility. The efforts centered around 1982. NAVSEA 503 (Crystal City) holds this room full of data; each shipyard involved likely has a file; and NAU MIT has a partial file of some of the documents. See reference [51] for a three page description of the DDG-51 producibility studies.

[117] Author(s): Editor
Title: "Team Play on Ships"
Mag/Publ: Business Week Date: 5/23/42 Pages: 1
Category: Wartime Producibility
Keywords: Liberty Outfit
Abstract: This brief article describes how the S.S. Oliver Hazard Perry (Liberty Ship) was built by California shipbuilding but outfitted by Consolidated Steel. The reason was primarily to provide early experience in outfitting to Consolidated for later use on its own production.

[118] Author(s): Editor
Title: "Twenty-four Ships a Month"
Mag/Publ: Business Week Date: 5/16/42 Pages: 2
Category: Wartime Producibility
Keywords: Series Liberty
Abstract: This article describes Higgins' wooden landing craft production and plans for a Liberty shipyard near New Orleans. The article is interesting as regards the planning of a new shipyard on short notice, and that later the shipyard project was cancelled.

[119] Author(s): Editor
Title: "Vertical Welding Machine Provides Savings for Shipbuilder"
Mag/Publ: Welding Journal Date: 2/70 Pages: 1
Category: Production Details
Keywords: Welding Electroslag Electrogas
Abstract: A portable electroslag/electrogas welding machine is used by Sun Ship for heavy 3-inch steel plate for oil tanker stern tubes and for tanker 50 foot vertical side shell seams. For the vertical seam, electrogas is used at a rate of 5 imp, and rise control is by rheostat or by electric eye.

[120] Author(s): Editor
Title: Welding Technique Saves Dollars
Mag/Publ: Marine Eng. Log Date: 7/80 Pages: 6
Category: Shipyard as Factory
Keywords: Modularity Welding Inland
Abstract: This article describes the modular hull construction technique newly instituted at Bay Shipbuilding, Sturgeon Bay, Wisconsin. One-hundred ton 'super-sections' are assembled with a 200 ton traveling overhead gantry crane. Bay Ship welding techniques and training are also discussed, especially a moisture-resistant electrode.

[121] Author(s): Editor
Title: "Will the New Welding Methods Contribute to Shipyard Profits?"
Mag/Publ: Marine Eng. Log   Date: 2/72   Pages: 5
Category: Shipyard as Factory
Keywords: Welding
Abstract: Briefly discusses the history of welding, but primarily discusses current welding processes, based upon a SNAME paper by R.C. McDermott. This article is a summary/overview, and contains some photos of automatic and semi-automatic welding methods.

[122] Author(s): -
Title: "PD-214:Multi-Purpose Mobilization Design"
Mag/Publ: U.S. Maritime Admin. Date: 11/78 Pages: -
Category: Wartime Producibility
Keywords: Austere Merchant
Abstract: This report presents a preliminary design in effort for a versatile mobilization ship. Extensive model tests have demonstrated the fine performance of the hull in calm water or waves.

[123] Author(s): -
Title: "AVMAST:SPC Education and Training Panel (SP-9) Videotape & Film Library"
Mag/Publ: SNAME, SPC   Date: -   Pages: -
Category: General
Keywords: Group/technology Outfit Modularity
Abstract: A collection of materials (tapes and slides, videotape, 8 mm and 16 mm film) that can be borrowed for $5/item for 21 days at a time. The subject is producibility with the same concentration as noted for the NSRP Microfiche Index [106]. Address: AVMAST, University of Michigan, 2901 Baxter Road, Ann Arbor, Michigan 48109, Attention: Michael Wade (313) 763-2465.

Appendix A

LIST OF PRODUCIBILITY IDEAS

This list is intended to provide a starting point for producibility studies. It is organized by the categories introduced in Chapter 3.

Fleet Concept	reference
Low mix ships	10,18,28,32,55,102
Single mission ships	10,33,70,102
Commercial standards	60,62
Changable payload	23
Arapaho	
Ready reserve	
Merchant fleet as auxiliaries	59
Mobilization	17,28,59,69,97,98,113,122
Distributed Production Facilities	8,79,80,93,113
Speed and Range requirements	16,21,32,82
Life Cycle vs. Acquisition Cost	

Preliminary Ship Layout	
Data Multiplex System	116
Reduce number of varieties of lube oil and reduce weight of lube oil carried	
Staggered bulkheads, paying structural penalty for increased arrangement efficiency	
Cable Banking	
Reduce deck heights	116
Make all decks parallel to baseline	116
Reduce number of foundations by direct mounting of lightweight items	
Improved power factors	
Dedicated Distributive System	72
Corrugated Panels	
Lightweight cabling	92,116
Fiber optics	90,96
Epoxy resin chocks	
Selected glass reinforced plastic (GRP) piping	116
High Strength Low Alloy (HSLA) steel	66
NAVTRUSS/SpaceTRUSS	35,116
Recessed niches for equipment in passageways to reduce average passageway width	

GRP panels	
Armored 'spine' for cabling	
Trade off long hull fuel efficiency for short hull structural efficiency	
Flat hull lines	65
Vertical armorred trunk	116
Machinery box tightness	116
Equipment removal routes	
SSES	51,116
Stanchion vs. stiffner tradeoff	
Multi-purpose electronics	33,43,92
Margins and standards	16,30,32,46,57
'No Frame' structural concept	72
Fuel efficient propulsion (diesels)	19,24,44,61,116
Alternate transmissions (electric)	52,63

<u>Production Details</u>

Standard structural details (penetrations, stiffener ends)	
Minimized lightening holes	
Semi-automatic welding	105,106,112,119,121
Standard structural parts (control panel mountings,etc.)	
Palletization to trade less man-hours for higher weight	23
Line heating (or laser) to shape structural plates	106

<u>Shipyard as Factory</u>

Computer-aided design (CAD) and computer-aided engineering	68,91,95
Zone outfitting	89,95,106,123
Accuracy control (for self and for subcontractors)	41,95,106,123
Digitized Contract Design Data	
Test Standards (that support zone outfitting, palletization)	31
Hardcopy to microfilm files	
Design/Production interface more but smaller drawings 3-D interactive drawings task-specific drawings	11
Models and mockups	123
Production flow, process lanes	26,64,95,106,123
Modular construction/heavy lift capability	14,23,36,58,68,93,120,123
Launching method	107

Early wet versus late wet production schedule	93
Numerical control	99,106,121

Economic Considerations

Make vs. buy	
Statistical management approach	7,15,79
Single vs. multi-source procurement	2,87
Contract incentives	87
Employee incentives	
Series production	2,69
Labor costs	8,57
Location as factor in labor costs and transportation costs	8
Work load distribution	2
Hire/fire policies	

Appendix B

PRODUCIBILITY ASSESSMENT, PAGE 2
(SHIP CHARACTERISTICS IMPACT) LISTING

```
SuperCalc Ver.  1.05
Figure 14: PRODUCIBILITY ASSESSMENT, page 2
A1       = "Figure 14: PRODUCIBILITY ASSESSMENT, page 2
A3       = "Ship Characteristics Impact
E3       = "Ship: BGASWFF
G3       = "Item:   1
A4       = "Concept: Deckheight Reduction w/ reverse framing; baseline=8'6", variant=9'0"
B6       = "parameter
C6       = "abbrev(dim)
D6       = " baseline
E6       = "  variant
F6       = "   delta
G6       = "  percent
B7       = "---------
C7       = "-----------
D7       = " --------
E7       = "  -------
F7       = "   -----
G7       = "  -------
A8       = "Length at waterline
C8       = "LWL  (feet)
D8       = 426.9
E8       = 429.7
F8       = E8-D8
G8       = F8/D8*100
A9       = "Length between perpendiculars
C9       = "LBP  (feet)
D9       = 426.9
E9       = 429.7
F9       = E9-D9
G9       = F9/D9*100
A10       = "Beam at waterline
C10       = "B    (feet)
D10       = 50.22
E10       = 50.55
F10       = E10-D10
G10       = F10/D10*100
A11       = "Depth amidships
C11       = "D    (feet)
D11       = 38.17
E11       = 38.42
F11       = E11-D11
G11       = F11/D11*100
A12       = "Draft
C12       = "T    (feet)
D12 $     = 18.83
E12 $     = 18.96
F12       = E12-D12
G12       = F12/D12*100
```

```
A13      = "Displacement, full load
C13      = "  fl    (LT)
D13      = 5558.3
E13      = 5668.5
F13      = E13-D13
G13      = F13/D13*100
A14      = "Volume of hull
C14      = "  h (k ft )
D14      = 558.15
E14      = 569.205
F14      = E14-D14
G14      = F14/D14*100
A15      = "Volume of deckhouse
C15      = "  dh(k ft )
D15      = 108.448
E15      = 116.369
F15      = E15-D15
G15      = F15/D15*100
A16      = "Total Volume
C16      = "  t (k ft )
D16      = 666.599
E16      = 685.574
F16      = E16-D16
G16      = F16/D16*100
A17      = "Stability measue
C17      = "GM/B   (-)
D17 G    = .1027
E17 G    = .0989
F17      = E17-D17
G17      = F17/D17*100
A18      = "Total electical load
C18      = "KW tot (KW)
D18      = 4105
E18      = 4133.1
F18      = E18-D18
G18      = F18/D18*100
A19      = "Main contin. power available
C19      = "IP     (hp)
D19      = 52209
E19      = 52514
F19      = E19-D19
G19      = F19/D19*100
A20      = "Manning
C20      = "N      (men)
D20      = 301
E20      = 301
F20      = E20-D20
G20      = F20/D20*100
A21      = "Maximum sustained speed
C21      = "Vs     (kts)
D21 $    = 27.95
E21 $    = 27.95
```

```
F21      = E21-D21
G21      = F21/D21*100
A22      = "Endurance speed
C22      = "Ve    (kts)
D22 $    = 20.0
E22 $    = 20.00
F22      = E22-D22
G22      = F22/D22*100
A23      = "Range
C23      = "R      (nm)
D23      = 4500
E23      = 4500
F23      = E23-D23
G23      = F23/D23*100
A24      = "Payload
C24      = "W payld(LT)
D24      = 970
E24      = 970
F24      = E24-D24
G24      = F24/D24*100
A25      = "Margins
C25      = "__________
F25      = E25-D25
C26      = "__________
A27      = "SWBS
B27      = "        Group
A28      = "----
B28      = "      ---------
A29      = " 100
B29      = "Hull Structure
C29      = "W1     (LT)
D29      = 1304.7
E29      = 1370
F29      = E29-D29
G29      = F29/D29*100
A30      = " 200
B30      = "Propulsion Plant
C30      = "W2     (LT)
D30      = 429
E30      = 433.7
F30      = E30-D30
G30      = F30/D30*100
A31      = " 300
B31      = "Electrical Plant
C31      = "W3     (LT)
D31      = 252
E31      = 256.1
F31      = E31-D31
G31      = F31/D31*100
A32      = " 400
B32      = "Command and Surveillence
C32      = "W4     (LT)
```

```
D32      = 650.2
E32      = 651.4
F32      = E32-D32
G32      = F32/D32*100
A33      = " 500
B33      = "Auxiliary Systems
C33      = "W5     (LT)
D33      = 639.6
E33      = 650.4
F33      = E33-D33
G33      = F33/D33*100
A34      = " 600
B34      = "Outfit and Furnishings
C34      = "W6     (LT)
D34      = 396.9
E34      = 403.4
F34      = E34-D34
G34      = F34/D34*100
A35      = " 700
B35      = "Armament
C35      = "W7     (LT)
D35      = 130
E35      = 130
F35      = E35-D35
G35      = F35/D35*100
A36      = " Weight of D+B margin
C36      = "Wm     (LT)
D36      = 475.3
E36      = 486.9
F36      = E36-D36
G36      = F36/D36*100
C37      = "===========
D37      = "   ======
E37      = "   ======
A38      = "LIGHTSHIP WEIGHT
C38      = "W ltshp(LT)
D38      = SUM(D29:D36)
E38      = SUM(E29:E36)
F38      = E38-D38
G38      = F38/D38*100
A39      = " Fuel & Lubricant weight
C39      = "Wf     (LT)
D39      = 1009.8
E39      = 1015.7
F39      = E39-D39
G39      = F39/D39*100
A40      = " Ordnance Load weight
C40      = "Wa     (LT)
D40      = 144.2
E40      = 144.3
F40      = E40-D40
G40      = F40/D40*100
```

```
A41      = " Other Load weight
C41      = "Wo     (LT)
D41      = 126.5
E41      = 126.5
F41      = E41-D41
G41      = F41/D41*100
C42      = "===========
D42      = "   ======
E42      = "   ======
A43      = "FULL LOAD WEIGHT
C43      = "W fl   (LT)
D43      = SUM(D38:D41)
E43      = SUM(E38:E41)
F43      = E43-D43
G43      = F43/D43*100
A45      = "Weight of primary 2-digit SWBS . . .
B46      = "        name
C46      = "subgroup
B47      = "        ----
C47      = "--------
B48      = "Shell and supports
C48 L    = 110
D48      = 389
E48      = 443.2
F48      = E48-D48
G48      = F48/D48*100
B49      = "Deckhouse structure
C49 L    = 150
D49      = 158
E49      = 173.1
F49      = E49-D49
G49      = F49/D49*100
C50 L    =
C51 L    =
A52      = "      note:small apparent summation errors are due to display roundoff.
```

Appendix C

PRODUCIBILITY ASSESSMENT, PAGE 3 (COST IMPACT) LISTING

This alternate method of computing acquisition cost within the Advanced Surface Ship Evaluation Tool (ASSET) is programmed using the commercial spreadsheet program 'Supercalc'. Supercalc creates a matrix with up to 64 columns and 254 rows, and each of the cells (intersection of a particular row number and column letter) can be filled with data. This data can take the form of an equation, numerical information, or text.

```
    | A || B || C || D || E | . . .
 1| ___  ___  ___  ___  ___
 2| ___  ___  ___  ___  ___
 3| ___  ___  ___  ___
 4| ___  ___  ___
 5| ___  ___
 .
 .
```

The listing that follows is for the program configured as in Figure 14. The program can be easily modified to work with other spreadsheets such as Lotus 1-2-3. The cell contents proceeded in the listing with "P=" are protected from alteration; the unprotected cells are to be filled with varying data for each of the various producibility concept studies.

```
SuperCalc Ver. 1.05

E1      P= "Figure 15:  PRODUCIBILITY ASSESSMENT, page 3
A3      P= "Ship Cost Impact (FY85 $)
J3       = "Ship: BGASWFF
L3       = "Item:   1
A4       = "Concept: Deckheight reduction w/ reverse framing; baseline=8'6", variant=9'0"
C6      P= "  ------- Baseline -----
F6      P= "  ------ Variant ------
I6      P= "Baseline
J6      P= " Variant
K6      P= "      k$
A7      P= "SWBS No.
B7      P= "Description
C7      P= "  Weight
D7      P= "    CERm
E7      P= "    CERh
F7      P= "   Weight
G7      P= "    CERm
H7      P= "    CERh
I7      P= " Cost,k$
J7      P= " Cost,k$
```

```
K7      P= "    delta
L7      P= "  percent
A8      P= "========
B8      P= "===========
C8      P= "  =======
D8      P= "   ======
E8      P= "   ======
F8      P= "  =======
G8      P= "   ======
H8      P= "   ======
I8      P= " =======
J8      P= " =======
K8      P= "    =====
L8      P= "  =======
A9      P= "11/12/13
B9      P= "HullMatl A
C9      P= 875.9
D9      P= 3.6
E9      P= 4.6
F9       = 920.9
G9       = 3.6
H9       = 4.52
I9      P= C9*(D9+E9)
J9      P= F9*(G9+H9)
K9      P= J9-I9
L9      P= (K9/I9)*100
A10     P= "11/12/13
B10     P= "HullMatl B
C10     P= 0
D10     P= 0
E10     P= 0
F10      = 0
G10      = 0
H10      = 0
I10     P= C10*(D10+E10)
J10     P= F10*(G10+H10)
K10     P= J10-I10
L10     P= 0
A11     P= "15
B11     P= "DkhsMatl A
C11     P= 158.3
D11     P= 5.5
E11     P= 7.4
F11      = 173.1
G11      = 5.5
H11      = 7.22
I11     P= C11*(D11+E11)
J11     P= F11*(G11+H11)
K11     P= J11-I11
L11     P= (K11/I11)*100
A12     P= "15
B12     P= "DkhsMatl B
C12     P= 0
```

```
D12     P= 0
E12     P= 0
F12      = 0
G12      = 0
H12      = 0
I12     P= C12*(D12+E12)
J12     P= F12*(G12+H12)
K12     P= J12-I12
L12     P= 0
A13     P= "162
B13     P= "Stacks
C13     P= 31.0
D13     P= 5.5
E13     P= 7.4
F13      = 32.8
G13      = 5.5
H13      = 7.4
I13     P= C13*(D13+E13)
J13     P= F13*(G13+H13)
K13     P= J13-I13
L13     P= (K13/I13)*100
A14     P= "171
B14     P= "Masts
C14     P= 10.7
D14     P= 5.5
E14     P= 7.4
F14      = 11.3
G14      = 5.5
H14      = 7.4
I14     P= C14*(D14+E14)
J14     P= F14*(G14+H14)
K14     P= J14-I14
L14     P= (K14/I14)*100
A15     P= "1X
B15     P= "Rest,Grp 1
C15     P= 228.8
D15     P= 2.9
E15     P= 4.3
F15      = 231.9
G15      = 2.9
H15      = 4.3
I15     P= C15*(D15+E15)
J15     P= F15*(G15+H15)
K15     P= J15-I15
L15     P= (K15/I15)*100
A16     P= "23  (hp)
B16     P= "Propul Units
C16     P= 52209
D16     P= .41
E16     P= .15
F16      = 52512
G16      = .41
H16      = .15
```

```
I16     P= C16*(D16+E16)
J16     P= F16*(G16+H16)
K16     P= J16-I16
L16     P= (K16/I16)*100
A17     P= "241
B17     P= "Reduc Gear
C17     P= 0
D17     P= 6
E17     P= 4
F17      = 0
G17      = 6
H17      = 4
I17     P= C17*(D17+E17)
J17     P= F17*(G17+H17)
K17     P= J17-I17
L17     P= 0
A18     P= "243
B18     P= "Shafting
C18     P= 78.7
D18     P= 31.0
E18     P= 4
F18      = 79.7
G18      = 31
H18      = 4
I18     P= C18*(D18+E18)
J18     P= F18*(G18+H18)
K18     P= J18-I18
L18     P= (K18/I18)*100
A19     P= "244
B19     P= "Bearings
C19     P= 14.6
D19     P= 32
E19     P= 4.5
F19      = 14.8
G19      = 32
H19      = 4.5
I19     P= C19*(D19+E19)
J19     P= F19*(G19+H19)
K19     P= J19-I19
L19     P= (K19/I19)*100
A20     P= "245
B20     P= "Propellers
C20     P= 31.8
D20     P= 2
E20     P= 4
F20      = 31.9
G20      = 2
H20      = 4
I20     P= C20*(D20+E20)
J20     P= F20*(G20+H20)
K20     P= J20-I20
L20     P= (K20/I20)*100
A21     P= "25
```

```
B21     P= "Support Sys
C21     P= 65.2
D21     P= 50
E21     P= 10
F21      = 67.2
G21      = 50
H21      = 10
I21     P= C21*(D21+E21)
J21     P= F21*(G21+H21)
K21     P= J21-I21
L21     P= (K21/I21)*100
A22     P= "26
B22     P= "Sup Sys-FO,LO
C22     P= 24.7
D22     P= 35
E22     P= 9
F22      = 24.8
G22      = 35
H22      = 9
I22     P= C22*(D22+E22)
J22     P= F22*(G22+H22)
K22     P= J22-I22
L22     P= (K22/I22)*100
A23     P= "2X
B23     P= "Rest,Grp 2
C23     P= 10.7
D23     P= 30
E23     P= 5
F23      = 10.7
G23      = 30
H23      = 5
I23     P= C23*(D23+E23)
J23     P= F23*(G23+H23)
K23     P= J23-I23
L23     P= (K23/I23)*100
A24     P= "31  (hp)
B24     P= "ElecPowerGen
C24     P= 4105
D24     P= .86
E24     P= .63
F24      = 4133
G24      = .86
H24      = .63
I24     P= C24*(D24+E24)
J24     P= F24*(G24+H24)
K24     P= J24-I24
L24     P= (K24/I24)*100
A25     P= "32
B25     P= "Power Distrib
C25     P= 92.8
D25     P= 20
E25     P= 40
F25      = 95.3
```

```
G25        = 20
H25        = 40
I25       P= C25*(D25+E25)
J25       P= F25*(G25+H25)
K25       P= J25-I25
L25       P= (K25/I25)*100
A26       P= "3X
B26       P= "Rest,Grp 3
C26       P= 63.2
D26       P= 20
E26       P= 40
F26        = 64.2
G26        = 20
H26        = 40
I26       P= C26*(D26+E26)
J26       P= F26*(G26+H26)
K26       P= J26-I26
L26       P= (K26/I26)*100
A27       P= "4
B27       P= "Command
C27       P= 650.2
D27       P= 15.6
E27       P= 23
F27        = 651.4
G27        = 15.6
H27        = 23
I27       P= C27*(D27+E27)
J27       P= F27*(G27+H27)
K27       P= J27-I27
L27       P= (K27/I27)*100
A28       P= "5
B28       P= "Auxiliary
C28       P= 639.6
D28       P= 28.5
E28       P= 19.3
F28        = 650.4
G28        = 28.5
H28        = 19.3
I28       P= C28*(D28+E28)
J28       P= F28*(G28+H28)
K28       P= J28-I28
L28       P= (K28/I28)*100
A29       P= "6
B29       P= "Outfit & furn
C29       P= 396.9
D29       P= 12.3
E29       P= 24.2
F29        = 403.4
G29        = 12.3
H29        = 24.2
I29       P= C29*(D29+E29)
J29       P= F29*(G29+H29)
K29       P= J29-I29
```

```
L29     P= (K29/I29)*100
A30     P= "7
B30     P= "Armament
C30     P= 130.0
D30     P= 3.6
E30     P= 7
F30      = 130
G30      = 3.6
H30      = 7
I30     P= C30*(D30+E30)
J30     P= F30*(G30+H30)
K30     P= J30-I30
L30     P= (K30/I30)*100
A31     P= "
B31     P= "D&B Margin
C31     P= 475.3
D31     P= 35.9
E31     P= 0
F31      = 486.9
G31      = 35.9
H31      = 0
I31     P= C31*(D31+E31)
J31     P= F31*(G31+H31)
K31     P= J31-I31
L31     P= (K31/I31)*100
A32     P= "--------
B32     P= "-------------
C32     P= "   ------
D32     P= "   ------
E32     P= "   ------
F32     P= "   ------
G32     P= "   ------
H32     P= "   ------
I32     P= "  -------
J32     P= "  -------
K32     P= "  -------
L32     P= "    -----
B33     P= "LIGHT SHIP
C33     P= SUM(C9:C15,C17:C23,C25:C31,C42,C43)
D33     P= "      na
E33     P= "       na
F33     P= SUM(F9:F15,F17:F23,F25:F31,D42,D43)
G33     P= "      na
H33     P= "       na
I33     P= SUM(I9:I31)
J33     P= SUM(J9:J31)
K33     P= J33-I33
L33     P= (K33/I33)*100
A34     P= "8
B34     P= "Engineering
C34     P= "   ditto
D34     P= 0
E34     P= 6.62
```

```
G34        = 0
H34        = 6.62
I34       P= C33*(D34+E34)
J34       P= F33*(G34+H34)
A35       P= "9
B35       P= "Assembly
C35       P= "   ditto
D35       P= 0
E35       P= 9.02
G35        = 0
H35        = 9.02
I35       P= C33*(D35+E35)
J35       P= F33*(G35+H35)
A36       P= "----------------------
C36       P= "  -------
D36       P= "  -------
E36       P= "  -------
G36       P= "  -------
H36       P= "  -------
I36       P= " ========
J36       P= " ========
A37       P= "ACQ.CONSTRUCTION COST
C37       P= "      na
D37       P= "      na
E37       P= "       na
G37       P= "      na
H37       P= "      na
I37       P= SUM(I33:I36)
J37       P= SUM(J33:J35)
K37 I     P= J37-I37
L37       P= (K37/I37)*100
A38       P= "
A39       P= "Weights for alternate costing SWBS No.
F39       P= "ACQ.CONSTRUCTION COST
I39       P= I37
J39       P= J37
K39 I     P= K37
L39       P= L37
A40       P= "SWBS No.
B40       P= "Description
C40       P= "Baseline
D40       P= " Variant
F40       P= "    plus profit %:
H40 L      = 8
I40       P= (H40/100)*I39
J40       P= (H40/100)*J39
K40 I     P= J40-I40
A41       P= "========
B41       P= "===========
C41       P= "========
D41       P= " =======
I41       P= " --------
J41       P= " --------
```

```
A42      = "23
B42      = "Propul Units
C42      = 203.3
D42      = 204.6
F42     P= "ACQ.CONSTRUCTION PRICE
I42     P= I39+I40
J42     P= J39+J40
K42 I   P= J42-I42
L42      = K42/I42*100
A43      = "31
B43      = "ElecPowerGen
C43      = 96
D43      = 96.6
F43     P= "   plus change orders
I43     P= I42*.08
J43     P= J42*.08
K43 I   P= J43-I43
F44     P= "   plus NAVSEA support
I44     P= I42*.025
J44     P= J42*.025
K44 I   P= J44-I44
A45     P= "SWBS No.
B45     P= "Description
C45     P= "Baseline
D45     P= " Variant
E45     P= "  %
F45     P= "   plus post delivery
I45     P= I42*.05
J45     P= J42*.05
K45 I   P= J45-I45
A46     P= "========
B46     P= "===========
C46     P= "========
D46     P= " =======
E46     P= " ===
F46     P= "   plus outfitting
I46     P= I42*.04
J46     P= J42*.04
K46 I   P= J46-I46
A47      = "11/12/13
B47      = "Hull Matl$
C47      = C9*D9
D47      = F9*G9
E47 L$  P= (D47-C47)/C47*100
F47     P= "   plus H/M/E + growth
I47     P= I42*.1
J47     P= J42*.1
K47 I   P= J47-I47
A48      = "15
B48      = "Dkhs Matl$
C48      = C11*D11
D48      = F11*G11
E48 L$  P= (D48-C48)/C48*100
```

```
F48     P= "  plus payload cost
I48     P= 276200
J48     P= 276200
K48     P= J48-I48
I49     P= " ========
J49     P= " ========
A50     P= "notes: acquisition costs are for
E50     P= "   UNIT SAILAWAY ACQ COST ($M)
I50     P= SUM(I42:I48)
J50     P= SUM(J42:J48)
K50 I   P= J50-I50
L50     P= K50/I50*100
A51     P= "       follow ship.O+S and LCC are
E51     P= "   OPER+SUPPORT SYSTEM COST ($M)
I51     P= 31221
J51      = 31289
K51     P= J51-I51
L51     P= K51/I51*100
A52     P= "       for 30 ships w/ 30 year life.
E52     P= "   AVG LIFE CYCLE COST/ship ($M)
I52     P= 1706
J52      = 1711
K52     P= J52-I52
L52     P= K52/I52*100
```

Appendix D

```
ASSET INPUT DATA FILE FOR BASELINE BATTLE GROUP ASW FRIGATE
SHIP REQ
  MISSION
     DESIGN MODE IND     = ENDURANCE
     ENDURANCE           = 4500.00
     DESIGN SPEED IND    = GIVEN
     DESIGN SPEED        = 27.95
     ENDURANCE SPEED IND = GIVEN
     ENDURANCE SPEED     = 20.00
  PAYLOAD: given in modified form in design summary menu number four
HULL
  HULL FORM GEOMETRY
    HULL SIZE IND        = CALC
    LBP                  =  426.900     FT
    HULL SHAPE IND       = CALC
    LBP/B                =  8.50000
    LBP/D                =  11.1840
    T/D                  = 0.493400
    LCB/LBP              = 0.503038
    PRISMATIC COEF       = 0.600000
    MAX SECTION COEF     = 0.803000
    HULL VOLUME          =  558150.     FT3
  HULL OFFSETS
    STATION ARRAY       (25X 1) = FT
 1 -17.38
 2 -7.723
 3  4.447
 4  21.64
 5  39.61
 6  58.37
 7  77.93
 8  102.1
 9  124.2
10  139.7
11  159.7
12  178.8
13  206.0
14  217.5
15  230.0
16  257.1
17  272.2
18  292.6
19  307.3
20  325.0
21  348.1
22  348.1
23  348.2
24  375.7
25  426.9
```

HALF BEAM ARRAY (25X11) = FT

1	0.3352E-02	0.3352E-02	0.3352E-02			
2	0.3352E-02	1.106	3.616			
3	0.3352E-02	2.246	7.433			
4	0.3352E-02	5.297	9.768	11.06	13.24	
5	0.3352E-02	5.766	10.39	13.24	15.72	17.20
	19.59					
6	0.3352E-02	8.213	14.25	18.51	21.63	22.70
	24.62					
7	0.3352E-02	7.744	13.91	17.60	20.65	22.96
	24.91	25.81	27.25			
8	0.3352E-02	7.543	13.78	17.97	21.25	23.37
	24.47	25.58	26.38	27.15	28.24	
9	0.3352E-02	7.778	14.25	19.28	22.70	24.31
	25.28	26.95	28.50			
10	0.3352E-02	10.06	16.76	20.10	22.28	23.36
	24.05	24.93	25.64	27.21	28.74	
11	0.3352E-02	6.705	12.87	18.61	22.46	23.97
	24.67	25.95	27.52	28.29	29.00	
12	0.3353E-02	7.878	14.58	19.71	22.53	23.97
	24.71	26.19	27.66	28.44	29.14	
13	0.3353E-02	7.878	14.58	20.12	22.76	24.17
	24.80	26.32	27.86	28.58	29.24	
14	1.073	10.06	16.76	20.78	22.89	24.14
	24.80	26.35	27.89	28.60	29.26	
15	1.073	9.588	15.19	20.12	22.39	23.90
	24.67	26.19	27.76	28.48	29.14	
16	1.073	10.06	16.76	20.12	22.46	24.14
	25.28	26.12	27.66	28.38	29.03	
17	1.073	10.06	16.76	20.12	22.46	23.80
	25.25	25.98	27.49	28.23	28.88	
18	1.073	10.06	16.76	20.12	22.26	24.14
	25.08	25.84	27.42	28.18	28.83	
19	1.073	10.06	16.76	20.33	22.40	23.50
	24.40	25.70	26.63	27.44	28.22	
20	1.025	9.324	15.17	18.99	21.09	22.09
	23.30	24.25	25.47	26.35	27.15	
21	1.073	6.705	13.41	16.25	18.68	20.31
	21.64	22.97	23.88	24.91	25.82	
22	1.073	6.705	13.41	16.25	18.68	20.31
	21.64	22.97	23.76	24.26	24.68	
23	1.073	6.705	13.41	16.25	18.68	20.31
	21.64	22.80	23.30			
24	1.073	6.705	12.40	14.68	16.79	18.50
	19.40	20.51	21.29			
25	1.073	5.364	10.63	13.41	15.09	15.59
	16.14	17.25	17.90			

WATERLINE ARRAY (25X11) = FT

1	48.68	48.70	49.72		
2	30.62	38.30	49.02		
3	13.11	31.13	48.22		
4	0.1005	23.31	36.15	39.42	46.21

```
  5 0.0000E+00  12.63      23.20      29.06      34.74      37.81
     44.40
  6 0.0000E+00  10.64      19.84      27.51      33.89      36.95
     42.69
  7 0.0000E+00  6.535      12.59      17.32      23.02      28.75
     33.44      36.53      41.18
  8 0.0000E+00  4.404      8.607      12.58      17.30      22.05
     25.95      30.35      33.25      36.23      39.68
  9 0.0000E+00  3.101      6.531      10.62      15.57      20.90
     25.64      33.12      38.17
 10 0.0000E+00  3.101      6.531      9.199      12.20      14.78
     17.29      21.94      25.90      33.08      38.17
 11 0.0000E+00  1.295      3.319      6.531      10.62      14.83
     18.56      25.91      33.07      36.13      38.17
 12 0.0000E+00  1.117      3.231      6.516      9.847      13.58
     17.01      25.06      31.37      34.93      38.17
 13 0.0000E+00  1.117      2.969      6.515      9.845      13.58
     17.00      25.04      31.33      34.83      38.17
 14 0.0000E+00  1.959      4.398      7.550      10.55      13.82
     17.00      25.05      31.36      34.84      38.17
 15 0.0000E+00  2.223      4.398      7.756      10.55      13.90
     17.00      25.05      31.36      34.84      38.17
 16  1.537      4.015      6.775      9.185      12.04      15.75
     20.86      24.97      31.34      34.83      38.17
 17  2.971      5.148      7.658      9.792      12.59      15.42
     20.67      24.87      31.33      34.83      38.17
 18  4.593      6.462      8.635      10.66      13.08      16.86
     20.44      24.76      31.31      34.83      38.17
 19  6.277      7.394      9.281      11.78      15.05      18.02
     21.64      27.27      31.29      34.82      38.17
 20  7.238      8.054      9.392      11.95      14.81      18.03
     22.16      26.11      31.21      34.82      38.17
 21  8.739      9.090      9.966      11.52      13.67      16.98
     21.27      27.05      31.08      34.82      38.17
 22  8.739      9.090      9.966      11.51      13.65      16.93
     21.13      26.75      30.63      32.32      33.90
 23  8.739      9.090      9.966      11.50      13.63      16.85
     20.94      26.33      29.63
 24  10.05      10.74      11.59      12.89      14.45      17.63
     21.37      26.29      29.63
 25  12.16      12.96      14.48      16.16      18.51      20.32
     22.53      27.05      29.63
  BILGE
     BILGE LOC IND         = CALC
     BILGE LOC ARRAY      (25X 1) =
  1 0.2000
  2 0.2000
  3 0.2000
  4 0.2000
  5 0.2000
  6 0.2000
  7 0.2000
```

```
 8 0.2000
 9 0.2000
10 0.2000
11 0.2000
12 0.2000
13 0.2000
14 0.2000
15 0.2000
16 0.2000
17 0.2000
18 0.2000
19 0.2000
20 0.2000
21 0.2000
22 0.2000
23 0.2000
24 0.2000
25 0.2000
    BILGE KEEL IND       = NONE
  MARGIN LINE
    MARGIN LINE IND      = CALC
    MIN FREEBOARD MARGIN = 0.250000     FT
    MARGIN LINE HT ARRAY(25X 1) = FT
 1  49.47
 2  48.77
 3  47.97
 4  45.96
 5  44.15
 6  42.44
 7  40.93
 8  39.43
 9  37.92
10  37.92
11  37.92
12  37.92
13  37.92
14  37.92
15  37.92
16  37.92
17  37.92
18  37.92
19  37.92
20  37.92
21  37.92
22  33.65
23  29.38
24  29.38
25  29.38
```

```
 HULL SUBDIVISION
   HULL SUBDIV IND       = GIVEN
   TRANS BHD SPACING     = 0.100000E+37
   TRANS BHD LOC ARRAY (16X 1) =
 1 0.4710E-01
 2 0.1059
 3 0.1647
 4 0.2235
 5 0.2941
 6 0.3529
 7 0.4647
 8 0.5353
 9 0.6059
10 0.6765
11 0.7471
12 0.8153
13 0.9059
   HULL AVG DECK HT      =  8.54305      FT
   HULL DECK LOC ARRAY ( 4X 1) = FT
 1  29.50
 2  21.00
 3  12.50
 4  4.000
   HULL DECK CONT ARRAY( 4X17) =
 1  1.000       1.000       1.000       1.000       1.000       1.000
    1.000       1.000       1.000       1.000       1.000       1.000
  0.0000E+00 0.0000E+00
 2  1.000       1.000       1.000       1.000       1.000       1.000
  0.0000E+00 0.0000E+00  1.000       1.000     0.0000E+00  1.000
    1.000       1.000
 3  1.000       1.000       1.000       1.000       1.000       1.000
  0.0000E+00 0.0000E+00  1.000       1.000     0.0000E+00  1.000
    1.000       1.000
 4  1.000       1.000       1.000       1.000       1.000       1.000
    1.000       1.000       1.000       1.000     0.0000E+00 0.0000E+00
  0.0000E+00 0.0000E+00
 HULL GIRDERS
   GDR INPUT IND         = CALC
   GDR LOC ARRAY       ( 3X 2) =
 1 0.0000E+00 0.6000
 2 0.0000E+00 0.6000
 3 0.0000E+00 0.6000
 HULL MATERIALS
   HULL MTRL TYPE IND   = HTS
   HULL MTRL DENSITY    =  489.024      LBM/FT3
   HULL MOD OF ELAS     =  29600.0      KSI
   HULL YIELD STRENGTH  =  45.0000      KSI
   HULL PROPORTNL LIMIT =  34.0000      KSI
   HULL MAX PRIM STRESS =  21.2800      KSI
   HULL ALW WORK STRESS =  38.0000      KSI
   HULL POISSONS RATIO  = 0.300000
```

```
  C COEF ARRAY        ( 3X 1) =
1 400.0
2 630.0
3 800.0
  HULL MARGINAL STRESS =  2.24000     KSI
 HULL LOADS
  HULL LOADS IND       = CALC
  DES BOT PRESS ARRAY ( 3X 1) = LBF/IN2
1 19.30
2 17.05
3 14.26
  DES SIDE PRESS ARRAY( 3X 1) = LBF/IN2
1 17.55
2 8.564
3 7.324
  DES DECK PRESS ARRAY( 3X 1) = LBF/IN2
1 5.333
2 1.778
3 1.778
  INT DECK PRESS ARRAY( 4X 1) = LBF/IN2
1 1.042
2 1.042
3 1.042
4 1.042
  HOGGING BM           =  86424.8     FT-LTON/IN
  SAGGING BM           =  72052.2     FT-LTON/IN
  SHOCK FOUNDATION IND = SHOCK
 HULL STRUCTURE
  BOT STRING SPACING   =  20.0000     IN
  SIDE STRING SPACING  =  20.0000     IN
  DECK STRING SPACING  =  20.0000     IN
  FRAME SPACING        =  4.00000     FT
  BOT GDR AREA ARRAY  ( 2X 1) = IN2
1 17.12
2 16.67
  DECK GDR AREA ARRAY ( 2X 1) = IN2
1 7.648
2 7.648
  FRAME AREA ARRAY    ( 3X 1) = IN2
1 5.108
2 4.367
3 5.794
  DECK BEAM AREA ARRAY( 3X 1) = IN2
1 4.482
2 1.986
3 1.852
  LWR BEAM AREA ARRAY ( 4X 1) = IN2
1 1.309
2 1.253
3 1.126
4 1.065
```

```
   LWR GDR AREA ARRAY  ( 4X 2) = IN2
1  4.258      4.258
2  2.344      2.344
3  4.258      4.258
4  6.963      6.963
   LWR SKIN THICK ARRAY( 4X 1) = IN
1 0.2202
2 0.1577
3 0.2202
4 0.2827
   BHD SKIN THICK ARRAY( 5X 1) = IN
1 0.1857
2 0.2513
3 0.2611
4 0.2828
5 0.3714
   AVG SKIN THICK ARRAY( 3X 3) = IN
1 0.3799     0.3296     0.3608
2 0.3799     0.3296     0.3608
3 0.3799     0.3296     0.3608
   MIDSHIP MOI            =  213570.     FT2-IN2
 DKHS GEOMETRY
   DKHS LOC ARRAY      (20X 1) =
1 0.2941
2 0.4176
3 0.2976
4 0.3012
   DKHS SIDE DIM ARRAY (20X 2) = FT
1 0.0000E+00 0.0000E+00
2 0.0000E+00 0.0000E+00
3 0.0000E+00 0.0000E+00
4  10.00      10.00
   DKHS HT ARRAY       (20X 1) = FT
1  8.500
2  17.00
3  8.500
4  8.500
   DKHS LENGTH ARRAY   (20X 1) =
1 0.1235
2 0.1170
3 0.1200
4 0.5880E-01
   WIND AREA FAC ARRAY ( 2X 1) =
1  1.250
2  1.250
   DKHS VOLUME           =  108448.     FT3
   DKHS VOLUME FRAC      = 0.194300
 DKHS MATERIALS
   DKHS MTRL TYPE IND    = HTS
   DKHS STRUCT DENSITY   =  4.18000     LBM/FT3
   FIRE PROTECTION IND   = NONE
```

```
PROPULSION PLANT
  MAIN ENGINE
    MAIN ENG SIZE IND     = CALC
    MAIN NO ENG           =  2.00000
    MAIN ENG TYPE IND     = GT
    MAIN CONT PWR AVAIL   =  26104.4     HP
    MAIN CONT RPM         =  3700.02
    MAIN ENG SFC          = 0.413282     LBM/HP-HR
    MAIN ENG SPEC WT      =  1.99000     LBM/HP
    MAIN CONT PWR REQ     =  20883.5     HP
    MAIN PWR MARGIN FAC   =  1.25000
  SEC ENGINE
    SEC ENG SIZE IND      =
    SEC NO ENG            = 0.100000E+37
    SEC ENG TYPE IND      = NONE
    SEC CONT PWR AVAIL    = 0.100000E+37 HP
    SEC CONT RPM          = 0.100000E+37
    SEC ENG SFC           = 0.100000E+37 LBM/HP-HR
    SEC ENG SPEC WT       = 0.100000E+37 LBM/HP
    SEC CONT PWR REQ      = 0.100000E+37 HP
    SEC PWR MARGIN FAC    = 0.100000E+37
  TRANSMISSION
    TRANS EFF IND         = CALC
    TRANS TYPE IND        = AC/AC
    DESIGN TRANS EFF      = 0.945000
    ENDURANCE TRANS EFF   = 0.930000
    GEAR K FAC            = 0.100000E+37 LBF/IN2
  MACHINERY ROOM
    MACHY BOX VOL IND     = CALC
    MACHY BOX VOL ARRAY ( 2X 1) =
 1 0.1251E+06
 2 0.0000E+00
    MAIN ENG CG IND       = CALC
    MAIN ENG CG ARRAY   ( 2X 1) =
 1 0.5700
 2 0.5600
    SEC ENG CG IND        = CALC
    SEC ENG CG ARRAY    ( 2X 1) =
 1 0.1000E+37
  POWERING
    NO PROP SHAFTS        =  2.00000
    THRUST DED COEF       = 0.106500
    TAYLOR WAKE FRAC      = 0.665000E-01
    REL ROTATE EFF        =  1.00000
    DESIGN DHP            =  19735.0     HP
    ENDURANCE DHP         =  4150.09     HP
  PROPELLER
    PROP TYPE IND         = FP
    PROP METHOD IND       = ANALYTIC
    PROP DIA IND          = CALC
    PROP DIA              =  16.1826     FT
```

```
   PROP AREA IND        = CALC
   EXPAND AREA RATIO    = 0.681855
   BACK CAV ALLOWED     =  10.0000
   NO BLADES            =  5.00000
   PITCH RATIO          =  1.43782
   DESIGN PROP RPM      =  140.000
   ENDURANCE PROP RPM   =  90.3249
   PROP RPM LIMIT ARRAY( 2X 1) =
 1  140.0
 2  180.0
   PROP LOC IND         = CALC
   PROP LOC ARRAY      ( 2X 1) =
 1 0.9499
 2 0.5317E-01
   PROP SYS DISP IND    = CALC
   PROP SYS DISP        =  38.7460     LTON
   PROP SYS CB ARRAY   ( 3X 1) = FT
 1  385.2
 2  12.14
 3  2.029
  OPEN WATER PROP DATA
   PROP ID IND          =
   ADVANCE COEF ARRAY  (10X 1) =
 1 0.4500
 2 0.5500
 3 0.6500
 4 0.7500
 5 0.8500
 6 0.9500
 7  1.050
 8  1.150
 9  1.250
10  1.350
   THRUST COEF ARRAY   (10X 6) =
 1 0.5081
 2 0.4735
 3 0.4355
 4 0.3948
 5 0.3517
 6 0.3065
 7 0.2597
 8 0.2117
 9 0.1628
10 0.1136
   TORQUE COEF ARRAY   (10X 6) =
 1 0.1086
 2 0.1022
 3 0.9526E-01
 4 0.8774E-01
 5 0.7968E-01
 6 0.7111E-01
 7 0.6203E-01
```

```
 8 0.5247E-01
 9 0.4244E-01
10 0.3196E-01
    PITCH RATIO ARRAY   ( 1X 6) =
 1  1.465
ELECTRIC PLANT
    GEN SIZE IND          = NON-STD
    GEN KW                =  1520.26
    GEN NO IND            = GIVEN
    NO SS GEN             =  4.00000
    SS ENG TYPE IND       = GT
    AVG 24 HR ELECT LOAD  =  2678.39
    TOTAL ELECT LOAD      =  4104.70
    ELECT MARGIN FAC      = 0.440000
    FREQ CONV IND         = NEW
COMMAND+SURVEILLANCE
  SONAR SYSTEM
    SONAR DOME IND        = PRESENT
    SONAR NAME TBL      ( 1X 4) =
 1 CONFORMAL AND TRANSMIT PLANAR ARRAYS
    SONAR WT ARRAY      ( 4X 1) = LTON
 1 0.0000E+00
 2  210.0
 3  200.0
 4 0.0000E+00
    SONAR KG ARRAY      ( 4X 1) = FT
 1 0.0000E+00
 2  5.000
 3  5.000
 4 0.0000E+00
    SONAR AREA ARRAY    ( 1X 2) = FT2
 1  495.0     0.0000E+00
    SONAR KW              =  400.000
    SONAR DISP            = 0.000000E+00 LTON
    SONAR CB ARRAY      ( 2X 1) = FT
 1  85.00
 2  5.000
    SONAR SECT AREA       = 0.000000E+00 FT2
    SONAR DRAG FAC ARRAY(31X 1) =
 1 0.0000E+00
 2 0.0000E+00
 3 0.0000E+00
 4 0.0000E+00
 5 0.0000E+00
 6 0.0000E+00
 7 0.0000E+00
 8 0.0000E+00
 9 0.0000E+00
10 0.0000E+00
11 0.0000E+00
12 0.0000E+00
13 0.0000E+00
```

```
14 0.0000E+00
15 0.0000E+00
16 0.0000E+00
17 0.0000E+00
18 0.0000E+00
19 0.0000E+00
20 0.0000E+00
21 0.0000E+00
22 0.0000E+00
23 0.0000E+00
24 0.0000E+00
25 0.0000E+00
26 0.0000E+00
27 0.0000E+00
28 0.0000E+00
29 0.0000E+00
30 0.0000E+00
31 0.0000E+00
AUXILIARY SYSTEMS
    VENT SYS IND         = STD
    FAN COIL IND         = PRESENT
    COLL PROTECT SYS IND = PARTIAL
    NO AUX BOILERS       = 0.000000E+00
    FIREMAIN SYS IND     = NEW
    PRAIRIE MASK SYS IND = PRESENT
    RUDDER SIZE IND      = CALC
    RUDDER AREA          =  225.107     FT2
    ROLL FIN AREA        =  70.0000     FT2
    NO FIN PAIRS         =  1.00000
    UNREP GEAR IND       = STREAM
    NO ANCHORS           =  2.00000
    POLLUTION CNTL IND   = PRESENT
OUTFIT+FURNISHINGS
    UNIT COMMANDER IND   = NONE
    CREW ACCOM ARRAY     ( 3X 1) =
 1  29.00
 2  21.00
 3  251.0
    HAB STANDARD FAC     = 0.000000E+00
    HAB OUTFIT IND       = MODERN
    STOWAGE TYPE IND     = VIDMAR
WEIGHT MARGINS
    GROWTH WT MARGIN     = 0.000000E+00 LTON
    D+B WT MARGIN IND    = FRACTION
    D+B WT MARGIN        =  475.306     LTON
    D+B WT MARGIN FAC    = 0.125000
    D+B KG MARGIN IND    = FRACTION
    D+B KG MARGIN        =  2.73538     FT
    D+B KG MARGIN FAC    = 0.125000
```

```
FULL LOADS
  STORES
    STORES PERIOD ARRAY ( 4X 1) =
 1  45.00
 2  30.00
 3  45.00
 4  45.00
  FUELS+LUBRICANTS
    USABLE FUEL WT       =  868.142     LTON
    FUEL LCG             = 0.500412
    BALLAST FUEL FRAC    = 0.100000E-02
RESISTANCE FACTORS
    FRICTION LINE IND    = ITTC
    DRAG MARGIN FAC      = 0.800000E-01
    NORM CURVE ARRAY    (31X 1) =
 1 0.9300
 2 0.9300
 3 0.9300
 4  1.025
 5  1.145
 6  1.137
 7  1.043
 8  1.020
 9  1.035
10  1.050
11  1.075
12  1.060
13  1.030
14  1.015
15  1.008
16  1.004
17 0.9700
18 0.9200
19 0.9000
20 0.8880
21 0.8880
22 0.8880
23 0.8880
24 0.8880
25 0.8880
26 0.8880
27 0.8880
28 0.8880
29 0.8880
30 0.8880
31 0.8880
    CORRELATION ALLOW    = 0.500000E-03
    DESIGN DRAG          =  330403.     LBF
    ENDURANCE DRAG       =  100951.     LBF
    DESIGN EHP EXPON     =  5.22098
    ENDURANCE EHP EXPON  =  4.50629
```

```
WEIGHT FACTORS
  SHIP WEIGHT
    SHIP LCG INPUT IND    = CALC
    FULL LOAD WT          =  5558.24     LTON
    FULL LOAD CG ARRAY  ( 2X 1) =
 1 0.5056
 2 0.5703
    SHIP WT ARRAY        ( 8X 1) = LTON
 1  1305.
 2  429.0
 3  252.0
 4  650.2
 5  639.6
 6  396.9
 7  130.0
 8  475.3
  WEIGHT ADJUSTMENTS
    WT ADJ ARRAY         ( 8X 1) = LTON
 1 -10.00
 2 0.0000E+00
 3 0.0000E+00
 4 0.0000E+00
 5 0.0000E+00
 6 0.0000E+00
 7 0.0000E+00
 8 0.0000E+00
    WT ADJ CG ARRAY      ( 8X 2) =
 1 0.5500      0.9000
 2 0.0000E+00 0.0000E+00
 3 0.0000E+00 0.0000E+00
 4 0.0000E+00 0.0000E+00
 5 0.0000E+00 0.0000E+00
 6 0.0000E+00 0.0000E+00
 7 0.0000E+00 0.0000E+00
 8 0.0000E+00 0.0000E+00
PERFORMANCE FACTORS
    SIG WAVE HT           = 0.100000E+37 FT
    MONTHS IN SERVICE     = 0.100000E+37
    SIG WAVE HT ARRAY   ( 5X 1) = FT
 1 0.1000E+37
    SEA STATE PROB ARRAY( 5X 1) =
 1 0.1000E+37
    MSN SPEED ARRAY     ( 5X 1) =
 1 0.1000E+37
    MSN SPEED PROB ARRAY( 5X 1) =
 1 0.1000E+37
    HULL FOULING FAC      = 0.100000E+37
    PROP FOULING FAC      = 0.100000E+37
    AVAIL FUEL FRAC       = 0.100000E+37
```

```
HYDROSTATIC FACTORS
 HYDROSTATIC BASELINE
   APPENDAGE IND        = WITH
   HYDROSTATIC IND      = FULL LOAD
   HYDROSTATIC DRAFT    = 0.100000E+37 FT
   HYDROSTATIC TRIM     = 0.100000E+37 FT
   HYDROSTATIC WT       = 0.100000E+37 LTON
   HYDROSTATIC LCG      = 0.100000E+37 FT
   HYDROSTATIC KG       = 0.100000E+37 FT
 FLOODABLE LENGTH
   FL LGTH PERM ARRAY  ( 4X 1) =
 1 0.1000E+37
 INTACT STABILITY
   INTACT WIND SPEED    =  100.000
   TURN RADIUS          = 0.100000E+37 FT
   TURN SPEED           = 0.100000E+37
 DAMAGED STABILITY
   COMP PERM ARRAY     (17X 1) =
 1 0.1000E+37
   COMP SYM INDEX ARRAY(17X 1) =
 1 0.1000E+37
   DAMAGED COMP ARRAY  (17X 1) =
 1 0.1000E+37
SPACE FACTORS
   VOL ADJ ARRAY       ( 4X 1) =
 1 0.0000E+00
 2 0.0000E+00
 3 0.0000E+00
 4 0.0000E+00
   SPACE MARGIN FAC     = 0.000000E+00
   PASSWAY MARGIN FAC   = 0.000000E+00
   DKHS AVG DECK HT     =  8.50000     FT
   REFER MACHY LOC IND  = INSIDE
COST FACTORS
 ECONOMIC FACTORS
   YEAR $               =  1985.00
   INFLATION RATE ARRAY(15X 1) =
 1 0.1000E+37
   PRODUCTION RATE      =  5.00000
   LEARNING RATE        = 0.970000
   FUEL COST            =  1.20000     $/GAL
 PAYLOAD COST FACTORS
   PAYLOAD T+E COST     =  43.6000
   LEAD PAYLOAD COST    =  307.900
   FOLLOW PAYLOAD COST  =  276.200
   ANNUAL TRNG ORD COST = 0.100000E+37
   PAYLOAD FUEL RATE    = 0.100000E+37 LTON/HR
 SHIP COST FACTORS
   IOC DATE             =  2005.00
   R+D PROGRAM LENGTH   =  5.00000
   NO OF SHIPS ACQUIRED =  30.0000
   PROFIT FRAC          = 0.800000E-01
```

```
   SERVICE LIFE         =  30.0000
   ANNUAL OPERATING HRS = 0.100000E+37
   TECH ADV COST        = 0.000000E+00
   ADDL FACILITY COST   = 0.000000E+00
   DEFERRED MNHRS REQ   = 0.000000E+00
   UNREP UNIT CAPACITY  = 0.100000E+37 LTON/YR
   UNREP UNIT COST      = 0.100000E+37
   UNREP O+S COST       = 0.100000E+37
   KN FACTOR ARRAY     ( 9X 1) =
 1 0.9830
 2  2.345
 3  1.000
 4  3.153
 5  1.528
 6  1.000
 7  1.000
 8  26.06
 9  4.254
   SHIP FUEL RATE       = 0.100000E+37 LTON/HR
MANNING FACTORS
   MANNING FACTOR ARRAY( 6X 1) =
 1 0.1000E+37
   WRKLOAD FACTOR ARRAY( 6X 1) =
 1 0.1000E+37
   AVIATION DEPT ARRAY ( 3X 1) =
 1  9.000
 2  3.000
 3  30.00
   NO WATCH STANDERS    = 0.100000E+37
```

BASELINE SHIP (BGASWFF) SELECTED ASSET OUTPUT MENUS

ASSET/MONOSC VERSION 1.2 - DESIGN SUMMARY - 5/ 1/85 11.10.07.

MENU ITEM NO. 2 - INDICATORS

MISSION
- DESIGN MODE-ENDURANCE
- DESIGN SPEED-GIVEN
- ENDURANCE SPEED-GIVEN

HULL
- HULL SIZE-CALC
- HULL SHAPE-CALC
- BILGE LOC-CALC
- BILGE KEEL-NONE
- MARGIN LINE-CALC
- HULL SUBDIV-GIVEN
- GDR INPUT-CALC
- HULL MTRL TYPE-HTS
- SHOCK FOUNDATION-SHOCK
- DKHS MTRL TYPE-HTS
- FIRE PROTECTION-NONE
- HULL LOADS-CALC

RESISTANCE FACTORS
- FRICTION LINE-ITTC

PROPULSION PLANT
- MAIN ENG SIZE-CALC
- MAIN ENG TYPE-GT
- SEC ENG SIZE-
- SEC ENG TYPE-NONE
- TRANS EFF-CALC
- TRANS TYPE-AC/AC
- MACHY BOX VOL-CALC
- MAIN ENG CG-CALC
- SEC ENG CG-CALC
- PROP TYPE-FP
- PROP METHOD-ANALYTIC
- PROP DIA-CALC
- PROP AREA-CALC
- PROP LOC-CALC
- PROP SYS DISP-CALC
- PROP ID-

ELECTRIC PLANT
- GEN SIZE-NON-STD
- GEN NO-GIVEN
- SS ENG TYPE-GT
- FREQ CONV-NEW

COMMAND+SURVEILLANCE
- SONAR DOME-PRESENT

AUXILIARY MACHINERY
- VENT SYS-STD
- FAN COIL-PRESENT
- COLL PROTECT SYS-PARTIAL
- FIREMAIN SYS-NEW
- PRAIRIE MASK SYS-PRESENT
- RUDDER SIZE-CALC
- UNREP GEAR-STREAM
- POLLUTION CNTL-PRESENT

OUTFIT+FURNISHINGS
- UNIT COMMANDER-NONE
- HAB OUTFIT-MODERN
- STOWAGE TYPE-VIDMAR

WEIGHT MARGINS
- D+B WT MARGIN-FRACTION
- D+B KG MARGIN-FRACTION

WEIGHT FACTORS
- SHIP LCG INPUT-CALC

MENU ITEM NO. 3 - MARGINS

HULL	
MIN FREEBOARD MARGIN, FT	0.25
HULL MARGINAL STRESS, KSI	2.24
PROPULSION PLANT	
MAIN PWR MARGIN FAC	1.250
SEC PWR MARGIN FAC	
ELECTRIC PLANT	
ELECT MARGIN FAC	0.440
WEIGHT MARGINS	
GROWTH WT MARGIN, LTON	0.000
D+B WT MARGIN, LTON	475.306
D+B WT MARGIN FAC	0.125
D+B KG MARGIN, FT	2.735
D+B KG MARGIN FAC	0.125
RESISTANCE FACTORS	
DRAG MARGIN FAC	0.080

MENU ITEM NO. 4 - PAYLOAD

	ROW	WT KEY	WT LTON	KG KEY	KG FT	AREA KEY	---AREA, FT2--- HULL/SS	SS ONLY	------KW------- CRUISE	MAX INC
	===	====	=======	====	=======	=====	=======	=======	=======	=======
	*	W165	0.00	BL	0.00					
	*	W460	210.00	BL	5.00	A1122	495.0	0.0	400.0	0.0
	*	W498	200.00	BL	5.00					
	*	W636	0.00	BL	0.00					
COMMAND&CONTROL	1	W410	9.70	D10	-21.00	A1131	1400.0	0.0	35.0	67.0
EXTERIOR COMMS	2	W440	14.30	D10	-21.00	A1111	540.0	0.0	7.0	18.0
SURF SEARCH/IFF	3	W450	4.80	D10	20.00	A1121	0.0	40.0	0.6	0.4
NAV RADAR	4	W450	0.10	D10	12.00	NONE	0.0	0.0	0.0	0.0
IR DETECTOR	5	W450	1.00	D10	12.00	A1121	0.0	40.0	0.0	0.0
TOWED ARRAY SONAR	6	W460	50.00	D20	-4.50	A1122	1200.0	0.0	0.0	0.0
ASW ELECTRONICS	7	W460	90.00	D6.5	-29.50	A1122	1800.0	0.0	0.0	0.0
ACTIVE ESM	8	W470	3.50	D10	20.00	A1141	0.0	200.0	5.0	40.0
ACOUSTIC DECOY	9	W470	2.30	D20	-6.50	A1142	185.0	0.0	1.7	0.0
GUN FIRE CONTROL	10	W480	5.00	D10	20.00	A1121	0.0	320.0	14.6	9.1
3 INCH GUN	11	W710	34.90	D6.5	4.00	A1210	432.0	0.0	8.0	20.0
2 20mm GUNS	12	W710	11.00	D10	21.00	NONE	0.0	0.0	11.0	14.0
32 CELL VLS	13	W720	64.50	D15	-11.00	A1220	1296.0	0.0	108.2	0.0
16 CELL VL AAW	14	W720	11.50	D3	-8.00	A1220	362.0	0.0	35.1	0.0
CHAFF DECOYS	15	W720	2.20	D10	19.00	NONE	0.0	0.0	0.8	0.6
TORP TUBES P&S	16	W750	4.00	D10	3.00	NONE	0.0	0.0	11.8	0.0
3 INCH AMMO	17	WF21	6.60	D6.5	-4.50	NONE	0.0	0.0	0.0	0.0
20mm AMMO	18	WF21	9.20	D10	12.50	A1210	0.0	144.0	0.0	0.0
ASW/SUW MISSILES	19	WF21	55.00	D15	-11.00	NONE	0.0	0.0	0.0	0.0
AAW MISSILES	20	WF21	3.90	D3	-8.00	NONE	0.0	0.0	0.0	0.0
CHAFF RSL	21	WF21	2.40	D10	19.00	NONE	0.0	0.0	0.0	0.0
TUBE TORPEDOES	22	WF21	1.40	D10	4.00	NONE	0.0	0.0	0.0	0.0
3 ASW HELOS	23	WF23	26.70	D10	5.00	NONE	0.0	0.0	0.0	0.0
HELO HANDL/STOW	24	W588	15.00	D15	-4.00	A1340	300.0	6000.0	28.0	0.0
HELO SUPPORT	25	WF26	12.00	D10	-6.00	A1390	240.0	360.0	2.0	3.0
HELO FUEL	26	WF42	95.00	BL	9.00	NONE	0.0	0.0	0.0	0.0
HELO TORPEDOES	27	WF22	12.00	D10	4.00	A1374	0.0	533.0	0.0	0.0
SONOBUOYS	28	WF26	12.00	D10	4.00	A1390	0.0	267.0	0.0	0.0

* DATA ARE EXTERIOR TO 'PAYLOAD' GROUP

ASSET/MONOSC VERSION 1.2 - DESIGN SUMMARY - 5/ 1/85 11.04.33.

MENU ITEM NO. 1 - SUMMARY

DESIGN SPEED, KT	27.95	LBP, FT	426.90
ENDURANCE SPEED, KT	20.00	BEAM (ON DWL), FT	50.22
ENDURANCE, NM	4500.	DEPTH (MIDSHIP), FT	38.17
MILITARY PAYLOAD, LTON	970.0	DRAFT (DWL), FT	18.83
CREW ACCOM	301.	SPACE MARGIN FAC	0.000
		HULL VOLUME, FT3	558150.
ALLOW PRIM STRESS, KSI	19.04	TOTAL SHIP VOL, FT3	666599.
MIDSHIP MOI, FT2-IN2	213570.		
		DESIGN DRAG, LBF	330403.
PROPELLER DIA, FT	16.18	ENDURANCE DRAG, LBF	100951.
NO PROP SHAFTS	2.		
DESIGN PROP RPM	140.0	LIGHTSHIP WT, LTON	4277.8
ENDURANCE PROP RPM	90.3	D+B WT MARGIN FAC	0.125
		USABLE FUEL WT, LTON	868.1
NO SS GEN	4.	FULL LOAD WT, LTON	5558.2
GEN KW, KW	1520.3	FULL LOAD KG, FT	21.77
TOTAL ELECT LOAD, KW	4104.7		
MAIN NO ENG	2.	NO ENG USED AT ENDURANCE	1.
MAIN CONT PWR AVAIL, HP	26104.	MAIN PWR MARGIN FAC	1.250
DESIGN CONT PWR REQ, HP	20884.	ENDURANCE CONT PWR REQ, HP	9817.

ASSET/MONOSC VERSION 1.2 - HULL GEOM MODULE - 5/ 1/85 11.05.32.

MENU ITEM NO. 1 - SUMMARY

HULL SIZE IND-CALC
HULL SHAPE IND-CALC

	INPUT HULL	OUTPUT HULL		
LBP, FT	426.90	426.90		
LBP/B	8.50	8.50		
LBP/D	11.18	11.18		
T/D	0.493	0.493		
LCB/LBP	0.503	0.503		
PRISMATIC COEF	0.600	0.600		
MAX SECTION COEF	0.803	0.803		
BEAM, FT	50.23		DISPLACEMENT, LTON	5558.5
DRAFT, FT	18.83		VOL OF DISPLACEMENT, FT3	194419.
DEPTH (MIDSHIP), FT	38.17		HULL VOLUME, FT3	558150.
LCB(FROM FP), FT	214.74		DECKHOUSE VOLUME, FT3	108448.
VCB(FROM BL), FT	12.12		TOTAL SHIP VOLUME, FT3	666599.
LCF(FROM FP), FT	229.62		TRANSVERSE KM, FT	26.93
AREA OF MAX AREA STA, FT2	759.5		LONGITUDINAL KM, FT	992.59
MAX AREA STA LOC FM FP,FT	197.51			
WATERPLANE AREA, FT2	17114.6		NUMBER INTERNAL DECKS	4
WETTED SURFACE, FT2	23582.8		NUMBER TRANS BKHDS	13

ASSET/MONOSC VERSION 1.2 - HULL STRUCT MODULE - 5/ 1/85 11.06.37.

MENU ITEM NO. 1 - SUMMARY

HULL LOADS IND-CALC   HULL MTRL TYPE IND-HTS   GDR INPUT IND-CALC

HULL MOD OF ELAS, KSI	29600.		HULL MTRL DENSITY, LBM/FT3	489.
HULL ALW WORK STRESS, KSI	38.00			
HULL MAX PRIM STRESS, KSI	21.28		HOGGING BM, FT-LTON	86425.
HULL MARGINAL STRESS, KSI	2.24		SAGGING BM, FT-LTON	72052.
			MIDSHIP MOI, FT2-IN2	213570.

ITEM	SPACING	NO.		
			DIST N.A. TO DECK, FT	17.6
			DIST N.A. TO KEEL, FT	20.6
TRANS BULKHEADS		13	SEC MOD TO DECK, FT-IN2	12128.
TRANS FRAMES, FT	4.0	94	SEC MOD TO KEEL, FT-IN2	10386.
INTERNAL DECKS		4		
LONGL GIRDERS		3	PRIM STRESS DECK-HOG, KSI	-15.96
BOTM STRINGERS, IN	20.0	24	PRIM STRESS KEEL-HOG, KSI	18.64
SIDE STRINGERS, IN	20.0	28	PRIM STRESS DECK-SAG, KSI	13.31
DECK STRINGERS, IN	20.0	30	PRIM STRESS KEEL-SAG, KSI	-15.54

PRESSURE, LBF/IN2	.25LBP	.50LBP	.75LBP
BOTTOM	19.30	17.05	14.26
SIDE	17.55	8.56	7.32
MAIN DECK	5.33	1.78	1.78
2ND DECK		1.04	
3RD DECK		1.04	
4TH DECK		1.04	
5TH DECK		1.04	

ASSET/MONOSC VERSION 1.2 - RESISTANCE MODULE - 5/ 1/85 11.11.09.

MENU ITEM NO. 1 - SUMMARY

FRICTION LINE IND-ITTC		FULL LOAD WT, LTON	5558.2
BILGE KEEL IND-NONE		FULL LOAD LCG/LBP	0.506
SONAR DOME IND-PRESENT		CORRELATION ALLOW	0.00050
RUDDER SIZE IND-CALC		DRAG MARGIN FAC	0.080
PROP TYPE IND-FP			

CONDITION	SPEED KT	DRAG,LBF FRIC	RESID	APPDG	WIND	MARGIN	TOTAL	EHP HP
DESIGN	27.95	101407.	182797.	16770.	4964.	24475.	330412.	28340.
ENDURANCE	20.00	53532.	31773.	5631.	2542.	7478.	100956.	6196.

ASSET/MONOSC VERSION 1.2 - PROPELLER MODULE - 5/ 1/85 11.11.37.

MENU ITEM NO. 1 - SUMMARY

PROP TYPE IND-FP	PROP METHOD IND-ANALYTIC
PROP DIA IND-CALC	PROP LOC IND-CALC
PROP AREA IND-CALC	PROP ID IND-

DESIGN SPEED, KT	27.95	ENDURANCE SPEED, KT	20.00
DESIGN DRAG, LBF	330412.	ENDURANCE DRAG, LBF	100956.
DESIGN DHP, HP	19735.5	ENDURANCE DHP, HP	4150.3
DESIGN PROP RPM	140.0	ENDURANCE PROP RPM	90.3
DESIGN PROP EFF	0.750	ENDURANCE PROP EFF	0.780
LBP, FT	426.90	DESIGN DRAFT, FT	18.83
PROP DIA, FT	16.18	PITCH RATIO	1.44
NO PROP SHAFTS	2.	NO BLADES	5.
EXPAND AREA RATIO	0.682	CAVITATION NO	1.65

ASSET/MONOSC VERSION 1.2 - MACHINERY MODULE - 5/ 1/85 11.14.52.

MENU ITEM NO. 1 - SUMMARY

MAIN ENG TYPE IND-GT	DESIGN MODE IND-ENDURANCE
MAIN ENG SIZE IND-CALC	PROP TYPE IND-FP
SEC ENG TYPE IND-NONE	TRANS TYPE IND-AC/AC
SEC ENG SIZE IND-	TRANS EFF IND-CALC
SS ENG TYPE IND-GT	GEN SIZE IND-NON-STD
DESIGN SPEED IND-GIVEN	GEN NO IND-GIVEN
ENDURANCE SPEED IND-GIVEN	SONAR DOME IND-PRESENT
MACHY BOX VOL IND-CALC	COLL PROTECT SYS IND-PARTIAL

DESIGN SPEED, KT	27.9	ENDURANCE SPEED, KT	20.0
DESIGN TRANS EFF	0.945	ENDURANCE TRANS EFF	0.930
DESIGN DHP, HP	19736.	ENDURANCE DHP, HP	4150.
MAIN NO ENG	2.	NO ENG USED AT ENDURANCE	1.
MAIN CONT PWR AVAIL/ENG, HP	26105.	MAIN PWR MARGIN FAC	1.25
MAIN CONT PWR REQ/ENG, HP	20884.	ENDURANCE PWR REQ, HP	9818.
NO PROP SHAFTS	2.	ENDURANCE, NM	4500.
TRANS REDUCTION RATIO	26.43	USABLE FUEL WT, LTON	868.2
TOTAL ELECT LOAD, KW	4105.	FUEL CONS, NM/LTON	5.2
AVG 24 HR ELECT LOAD, KW	2678.		

ASSET/MONOSC VERSION 1.2 - SPACE ANALYSIS - 5/ 1/85 11.16.14.

MENU ITEM NO. 1 - SUMMARY

MAIN ENG TYPE-GT	MACHY BOX VOL-CALC	UNIT COMMANDER-NONE
SEC ENG TYPE-NONE	REFER MACHY LOC-INSIDE	SONAR DOME-PRESENT
SS ENG TYPE-GT	FREQ CONV-NEW	

FULL LOAD WT, LTON	5558.2	NO. OFFICER ACC	29.
DKHS AVG DECK HT, FT	8.50	NO. CPO ACC	21.
HULL AVG DECK HT, FT	8.54	NO. CREW ACC	251.
PASSWAY MARGIN FAC	0.000	TOT ELECT SYS KW AVAIL	6081.
SPACE MARGIN FAC	0.000	TOT CONT HP AVAIL	52210.
HAB STANDARD FAC	0.000		

	AREA FT2		VOL FT3	
	PAYLOAD REQUIRED	TOTAL REQUIRED	TOTAL ACTUAL	TOTAL REQUIRED
DECKHOUSE	7904.	16881.	108448.	143489.
HULL	8250.	43920.	558150.	517705.
TOTAL	16154.	60801.	666599.	661194.

SSCS GROUP	AREA FT2	VOL FT3	PERCENT-VOL	VOL ADJ FT3
1. MISSION SUPPORT	17456.	148759.	22.5	0.
2. HUMAN SUPPORT	15681.	136402.	20.6	0.
3. SHIP SUPPORT	21663.	198936.	30.1	0.
4. SHIP MOBILITY SYSTEM	6002.	177097.	26.8	0.
5. UNASSIGNED	0.	0.	0.0	
TOTAL	60801.	661194.	100.0	0.

WARNING NO. 1 - COST ANALYSIS MODULE
DEFAULT VALUES WERE PROVIDED THE FOLLOWING PARAMETERS-

INFLATION RATE ARRAY	ANNUAL TRNG ORD COST	PAYLOAD FUEL RATE
ANNUAL OPERATING HRS	UNREP UNIT CAPACITY	UNREP UNIT COST
UNREP O+S COST	SHIP FUEL RATE	

ASSET/MONOSC VERSION 1.2 - COST ANALYSIS - 5/ 1/85 11.17.32.

NOTE-THIS INTERIM MODULE PROVIDES GUIDANCE FOR DECISIONS REGARDING SHIP DESIGN TRADEOFFS AND COMPARATIVE EVALUATIONS. REQUESTS FOR ESTIMATES OF SHIP COSTS FOR BUDGETARY PURPOSES SHOULD BE DIRECTED TO NAVSEA.

MENU ITEM NO. 1 - SUMMARY

YEAR $	1985.	NO OF SHIPS ACQUIRED	30.
INFLATION ESCALATION FAC	1.433	SERVICE LIFE, YR	30.0
LEARNING RATE	0.970	ANNUAL OPERATING HRS	2500.0
FUEL COST, $/GAL	1.200	MILITARY P/L, LTON	970.0
PAYLOAD FUEL RATE, LTON/HR	0.33	LIGHTSHIP WT, LTON	4277.8
SHIP FUEL RATE, LTON/HR	3.86	FULL LOAD WT, LTON	5558.2

COST ITEM	COSTS(MILLIONS OF DOLLARS) TOT SHIP	+ PAYLOAD	= TOTAL
LEAD SHIP	664.0	307.9	971.9
FOLLOW SHIP	308.3	276.2	584.5
AVG ACQUISITION COST/SHIP(30 SHIPS)	282.4	277.3	559.7
LIFE CYCLE COST/SHIP(30 YEARS)			1705.6
TOTAL LIFE CYCLE COST(30 YEARS)			51169.1
DISCOUNTED LIFE CYCLE COST/SHIP**			86.5
DISCOUNTED TOTAL LIFE CYCLE COST**			2596.5

**DISCOUNTED AT 10 PERCENT

ASSET/MONOSC VERSION 1.2 - WEIGHT MODULE - 5/ 1/85 10.45.53.

MENU ITEM NO. 1 - SUMMARY

		W E I G H T		CG-FT		W G T	A D J	
SWBS	G R O U P	LTON	PER CENT	VERT	LONG	LTON	VERT	LONG
====	=========	====	========	====	====	====	====	====
100	HULL STRUCTURE	1304.7	23.5	24.4	208.8	-10.0	34.4	234.8
200	PROP PLANT	429.0	7.7	17.4	297.9	0.0	0.0	0.0
300	ELECT PLANT	252.0	4.5	23.6	243.3	0.0	0.0	0.0
400	COMM + SURVEIL	650.2	11.7	10.9	162.2	0.0	0.0	0.0
500	AUX SYSTEMS	639.6	11.5	24.0	234.8	0.0	0.0	0.0
600	OUTFIT + FURN	396.9	7.1	27.3	213.4	0.0	0.0	0.0
700	ARMAMENT	130.0	2.3	35.6	192.1	0.0	0.0	0.0
M11	D+B MARGINS	475.3	8.6	21.9	217.5			
	D+B KG MARGIN			2.7				
	L I G H T S H I P	4277.8	77.0	24.6	217.5	-10.0	34.4	234.8
F00	FULL LOADS	1280.5	23.0	12.3	210.4	0.0	0.0	0.0
F10	CREW + EFFECTS	33.9		27.9	200.6			
F20	MISS REL EXPEN	144.2		35.8	187.8			
F30	SHIPS STORES	42.9		21.0	230.5			
F40	FUELS + LUBRIC	1009.8		8.3	213.7			
F50	FRESH WATER	49.7		5.2				
F60	CARGO	0.0		0.0				
M24	FUTURE GROWTH	0.0		0.0	0.0			
	FULL LOAD WT	5558.2	100.0	21.8	215.8	-10.0	34.4	234.8

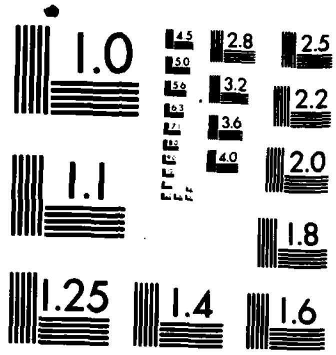
MENU ITEM NO. 2 - HULL STRUCTURES

SWBS	COMPONENT	WGT-LTON	CGZ-FT	CGX-FT
====	=========	========	======	======
100	HULL STRUCTURES	1304.7	24.4	208.8
110	SHELL + SUPPORTS	388.8	17.3	
111	PLATING	263.8	17.1	
115	STANCHIONS	6.0	19.1	
116	LONG FRAMING	34.3	5.5	
117	TRANS FRAMING	84.7	22.3	
120	HULL STRUCTURAL BULKHDS	136.1	22.0	
121	LONG BULKHDS	38.8	22.0	
122	TRANS BULKHDS	77.5	22.0	
123	TRUNKS + ENCLOSURES	19.8	22.0	
130	HULL DECKS	351.0	27.2	
131	MAIN DECK	150.2	37.9	
132	2ND DECK	77.0	29.4	
133	3RD DECK	42.5	20.9	
134	4TH DECK	45.7	12.4	
135	5TH DECK	35.6	3.8	

AD-A159 011 PRODUCIBILITY AS A DESIGN FACTOR IN NAVAL COMBATANTS (U) MASSACHUSETTS INST OF TECH CAMBRIDGE DEPT OF OCEAN ENGINEERING M L BOSWORTH JUN 85 N66314-70-A-0073 3/3

UNCLASSIFIED F/G 13/10 NL

END



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

150	DECK HOUSE STRUCTURE	158.3	47.6	
160	SPECIAL STRUCTURES	31.0	25.9	
160+	CLOSURES, STACKS, ETC	31.0	25.9	
*164	BALLISTIC PLATING	0.0	0.0	
*165	SONAR DOMES	0.0	0.0	
170	MASTS, KINGPOSTS, ETC	10.7	103.1	
180	FOUNDATIONS	225.9	15.3	
182	PROPULSION PLANT	72.7	9.4	
183	ELECTRIC PLANT	33.0	18.5	
184	C + S	37.0	12.6	
185	AUX. SYSTEMS	64.0	17.9	
186	OUTFIT + FURNISHINGS	9.5	29.3	
187	ARMAMENT	9.7	28.9	
190	SPECIAL PURPOSE SYSTEMS	13.0	4.0	
191	BALLAST+BOUYANCY	0.0	0.0	
198	FREE FLOODING LIQUIDS	13.0	4.0	
1XX	WEIGHT ADJUSTMENT	-10.0	34.4	234.8

(* DENOTES USER INPUT ITEM)

MENU ITEM NO. 3 - PROPULSION PLANT

SWBS	COMPONENT	WGT-LTON	CGZ-FT	CGX-FT
====	=========	========	======	======
200	PROPULSION PLANT	429.0	17.4	297.9
230	PROPULSION UNITS	203.3	16.8	
231	STEAM COMP FOR COGAS	0.0	0.0	
233	DIESEL ENGINES	0.0	0.0	
234	GAS TURBINES	47.0	21.4	
235	ELECTRIC PROPULSION	156.4	15.5	
	PROP MOTORS	60.9	11.5	
	PROP GENERATORS	23.8	21.4	
	TRANSMISSION LINES	56.2	16.4	
	COOLING SYSTEMS	6.1	16.4	
	SWITCH GEAR	9.3	20.6	
*237	AUXILIARY PROPULSION	0.0	0.0	
240	TRANS + PROPULSOR	125.2	5.3	
241	REDUCTION GEARS	0.0	0.0	
242	CLUTCHES + COUPLINGS	0.0	0.0	
243	SHAFTING	78.7	6.6	
244	SHAFT BEARINGS	14.6	5.0	
245	PROPELLERS	31.8	2.0	
250	SUPPORT SYSTEMS	65.2	43.5	
251	COMBUSTION AIR	21.6	46.0	
252	CONTROLS	8.1	27.5	
256	CIRC + COOL SEA WATER	0.5	11.5	
259	UPTAKES	35.0	46.0	
260	SUP SYS- FUEL, LUBE OIL	24.7	16.3	
261	FUEL SERVICE	6.1	12.6	
262	MAIN PROP LUBE OIL	12.8	16.4	
264	LUBE OIL HANDLING	5.8	19.8	
290	SPECIAL PURPOSE SYSTEMS	10.5	14.4	

298	OPERATING FLUIDS	6.5	10.3	
299	REPAIR PARTS + TOOLS	4.1	21.0	
2XX	WEIGHT ADJUSTMENT	0.0	0.0	0.0

(* DENOTES USER INPUT ITEM)

MENU ITEM NO. 4 - ELECTRIC PLANT

SWBS	COMPONENT	WGT-LTON	CGZ-FT	CGX-FT
====	=========	========	======	======
300	ELECTRIC PLANT, GENERAL	252.0	23.6	243.3
310	ELECTRIC POWER GENERATION	96.0	18.8	
311	SHIP SERVICE PWR GEN	76.0	16.1	
313	BATTERIES+SERVICE PWR GEN	2.3	25.2	
314	POWER CONVERSION EQUIPMENT	17.6	29.4	
320	POWER DISTRIBUTION SYS	92.8	23.9	
321	SS POWER CABLE	53.5	23.5	
323	CASUALTY POWER CABLE SYS	2.9	25.9	
324	SWITCH GEAR+PANELS	36.5	24.3	
330	LIGHTING SYSTEM	21.2	30.4	
331	LIGHTING DISTRIBUTION	12.2	29.9	
332	LIGHTING FIXTURES	9.0	31.1	
340	POWER GENERATION SUPPORT SYS	36.9	32.3	
342	DIESEL SUPPORT SYS	0.0	0.0	
343	TURBINE SUPPORT SYS	36.9	32.3	
390	SPECIAL PURPOSE SYS	5.2	20.3	
398	ELECTRIC PLANT OP FLUIDS	0.6	16.8	
399	REPAIR PARTS+SPECIAL TOOLS	4.6	20.8	
3XX	WEIGHT ADJUSTMENT	0.0	0.0	0.0

MENU ITEM NO.5 - COMMAND+SURVEILLANCE, GENERAL

SWBS	COMPONENT	WGT-LTON	CGZ-FT	CGX-FT
====	=========	========	======	======
400	COMMAND+SURVEILLANCE	650.2	10.9	162.2
*410	COMMAND+CONTROL SYS	9.7	17.2	
420	NAVIGATION SYS	7.8	51.2	
430	INTERIOR COMMUNICATIONS	25.2	25.7	
*440	EXTERIOR COMMUNICATIONS	14.3	17.2	
*450	SURF SURV SYS (RADAR)	5.9	56.7	
*460	UW SURV SYS (SONAR)	350.0	8.8	
470	COUNTERMEASURES	32.4	29.0	
*470+	ACTIVE/PASSIVE ECM, DEGAUSING, ETC	5.8	44.3	
475	DEGAUSING	26.6	25.7	
*480	FIRE CONTROL SYS	5.0	58.2	
490	SPECIAL PURPOSE SYS	200.0	5.0	
*490+	ELECT TEST, MONITOR, DATA PROC, ETC	0.0	0.0	
*498	C+S OPERATING FLUIDS	200.0	5.0	
4XX	WEIGHT ADJUSTMENT	0.0	0.0	0.0

(* DENOTES USER INPUT ITEM)

ASSET/MONOSC VERSION 1.2 - WEIGHT MODULE - 5/ 1/85 10.55.10.

MENU ITEM NO. 6 - AUXILIARY SYSTEMS

SWBS	COMPONENT	WGT-LTON	CGZ-FT	CGX-FT
====	=========	========	======	======
500	AUXILIARY SYSTEMS, GENERAL	639.6	24.0	234.8
510	CLIMATE CONTROL	150.3	24.9	
511	COMPARTMENT HEATING SYS	6.8	26.8	
512	VENTILATION SYS	47.2	33.8	
513	MACHINERY SPACE VENT SYS	8.4	33.3	
514	AIRCONDITIONING SYS	66.7	20.3	
516	REFRIGERATION SYS	3.6	14.0	
517	AUX BOILERS+OTHER HEAT SOURCES	17.5	16.1	
520	SEA WATER SYS	83.9	22.6	
521	FIREMAIN+SEA WATER FLUSHING SYS	53.3	22.6	
522	SPRINKLING SYS	3.5	27.3	
523	WASHDOWN SYS	1.8	43.5	
526	SCUPPERS+DECK DRAINS	1.3	38.2	
528	PLUMBING DRAINAGE	13.3	25.4	
529	DRAINAGE+BALLASTING SYS	10.7	12.7	
530	FRESH WATER SYS	45.3	27.7	
531	DISTILLING PLANT	6.9	21.0	
532	COOLING WATER	18.0	38.2	
533	POTABLE WATER	11.7	23.5	
534	AUX STEAM + DRAINS IN MACH BOX	8.7	16.8	
540	FUELS/LUBRICANTS,HANDLING+STORAGE	46.4	15.9	
541	SHIP FUEL+COMPENSATING SYS	41.7	15.3	
542	AVIATION+GENERAL PURPOSE FUELS	4.7	21.8	
550	AIR,GAS+MISC FLUID SYS	55.5	24.0	
551	COMPRESSED AIR SYS	37.2	22.4	
*553	O2/N2 SYS	0.0	0.0	
555	FIRE EXT SYS	18.3	27.3	
560	SHIP CNTL SYS	91.5	12.7	
561	STEERING+DIVING CNTL SYS	18.6	21.0	
562	RUDDER	37.9	14.0	
566	DIVING PLANES+STABILIZATION FINS	35.0	7.0	
570	UNDERWAY REPLENISHMENT SYS	20.0	35.0	
571	REPLENISHMENT-AT-SEA SYS	11.8	37.9	
572	SHIP STORES+EQUIP HANDLING SYS	8.1	30.7	
580	MECHANICAL HANDLING SYS	90.0	37.9	
581	ANCHOR HANDLING+STOWAGE SYS	38.7	29.6	
582	MOORING+TOWING SYS	7.7	36.2	
583	BOAT HANDLING+STOWAGE SYS	28.6	51.5	
*588	AIRCRAFT HANDLING,SERVICING,STOWAGE	15.0	34.2	
590	SPECIAL PURPOSE SYS	56.8	19.5	
593	ENVIRONMENTAL POLLUTION CNTL SYS	8.1	9.0	
598	AUX SYS OPERATING FLUIDS	45.4	21.4	
599	AUX SYS REPAIR PARTS+TOOLS	3.3	19.8	
5XX	WEIGHT ADJUSTMENT	0.0	0.0	0.0

(* DENOTES USER INPUT ITEM)

MENU ITEM NO. 7 - OUTFIT+FURNISHINGS

SWBS	COMPONENT	WGT-LTON	CGZ-FT	CGX-FT
====	=========	========	======	======
600	OUTFIT+FURNISHING,GENERAL	396.9	27.3	213.4
610	SHIP FITTINGS	15.0	42.9	
611	HULL FITTINGS	6.1	35.1	
612	RAILS,STANCHIONS+LIFELINES	7.1	45.8	
613	RIGGING+CANVAS	1.8	58.0	
620	HULL COMPARTMENTATION	78.6	22.4	
621	NON-STRUCTURAL BULKHEADS	25.2	29.9	
622	FLOOR PLATES+GRATING	40.2	15.3	
623	LADDERS	7.1	26.8	
624	NON-STRUCTURAL CLOSURES	4.9	29.1	
625	AIRPORTS,FIXED PORTLIGHTS,WINDOWS	1.1	51.5	
630	PRESERVATIVES+COVERINGS	126.8	31.3	
631	PAINTING	33.3	20.6	
633	CATHODIC PROTECTION	1.1	6.0	
634	DECK COVERINGS	26.4	27.2	
635	HULL INSULATION	34.2	47.2	
*636	HULL DAMPING	0.0	0.0	
637	SHEATHING	24.7	33.3	
638	REFRIGERATION SPACES	7.2	18.1	
640	LIVING SPACES	49.2	26.1	
641	OFFICER BERTHING+MESSING	10.8	36.4	
642	NON-COMM OFFICER B+M	4.5	27.9	
643	ENLISTED PERSONNEL B+M	26.9	21.6	
644	SANITARY SPACES+FIXTURES	4.3	23.2	
645	LEISURE+COMMUNITY SPACES	2.8	31.3	
650	SERVICE SPACES	22.6	28.2	
651	COMMISSARY SPACES	10.4	30.9	
652	MEDICAL SPACES	2.6	27.8	
654	UTILITY SPACES	1.3	31.3	
655	LAUNDRY SPACES	5.3	24.4	
656	TRASH DISPOSAL SPACES	3.0	24.5	
660	WORKING SPACES	31.3	29.1	
661	OFFICES	8.5	28.0	
662	MACH CNTL CENTER FURNISHING	1.3	20.5	
663	ELECT CNTL CENTER FURNISHING	6.9	39.4	
664	DAMAGE CNTL STATIONS	3.7	31.5	
665	WORKSHOPS,LABS,TEST AREAS	10.8	23.7	
670	STOWAGE SPACES	70.5	22.0	
671	LOCKERS+SPECIAL STOWAGE	12.7	30.0	
672	STOREROOMS+ISSUE ROOMS	57.8	20.3	
690	SPECIAL PURPOSE SYSTEMS	2.9	23.6	
698	OPERATING FLUIDS	0.3	27.3	
699	REPAIR PARTS+SPECIAL TOOLS	2.6	23.2	
6XX	WEIGHT ADJUSTMENT	0.0	0.0	0.0

(* DENOTES USER INPUT ITEM)

MENU ITEM NO. 8 - ARMAMENT

SWBS	COMPONENT	WGT-LTON	CGZ-FT	CGX-FT
====	=========	========	======	======
700	ARMAMENT	130.0	35.6	192.1
*710	GUNS+AMMUNITION	45.9	46.2	
*720	MISSLES+ROCKETS	78.2	29.1	
*750	TORPEDOES	4.0	41.2	
760	SMALL ARMS+PYROTECHNICS	1.9	34.7	
761	LAUNCHING DEVICES	1.0	34.7	
763	SMALL ARMS+PYRO STOWAGE	0.9	34.7	
*780	AIRCRAFT RELATED WEAPONS	0.0	0.0	
*790	SPECIAL PURPOSE SYSTEMS	0.0	0.0	
7XX	WEIGHT ADJUSTMENT	0.0	0.0	0.0

(* DENOTES USER INPUT ITEM)

MENU ITEM NO. 9 - LOADS (FULL LOAD CONDITION)

SWBS	COMPONENT	WGT-LTON	CGZ-FT	CGX-FT
====	=========	========	======	======
F00	LOADS	1280.5	12.3	210.4
F10	SHIPS FORCE	33.9	27.9	200.6
F11	OFFICERS	5.0	27.9	
F12	NON-COMMISSIONED OFFICERS	3.1	27.9	
F13	ENLISTED MEN	25.8	27.9	
F20	MISSION RELATED EXPENDABLES+SYS	144.2	35.8	187.8
*F21	SHIP AMMUNITION	78.5	32.0	
*F22	ORD DEL SYS AMMO	12.0	42.2	
*F23	ORD DEL SYS (AIRCRAFT)	26.7	43.2	
*F24	ORD REPAIR PARTS (SHIP)	0.0	0.0	
*F25	ORD REPAIR PARTS (ORD)	0.0	0.0	
*F26	ORD DEL SYS SUPPORT EQUIP	24.0	37.2	
F29	SPECIAL MISSION RELATED SYS	3.0	34.7	
F30	STORES	42.9	21.0	230.5
F31	PROVISIONS+PERSONNEL STORES	35.0	20.5	
F32	GENERAL STORES	7.9	23.2	
F40	LIQUIDS, PETROLEUM BASED	1009.8	8.3	213.7
F41	DIESEL FUEL MARINE	913.8	8.2	
*F42	JP-5	95.0	9.0	
F46	LUBRICATING OIL	0.9	20.8	
F50	LIQUIDS, NON-PETRO BASED	49.7	5.2	
F52	FRESH WATER	44.7	5.3	
F53	RESERVE FEED WATER	5.0	5.0	
*F60	CARGO	0.0	0.0	
FXX	WEIGHT ADJUSTMENT	0.0	0.0	0.0
*M24	FUTURE GROWTH MARGIN	0.0	0.0	0.0

(* DENOTES USER INPUT ITEM)

Appendix E

DECKHEIGHT VARIANT (9') SELECTED ASSET OUTPUT MENUS

ASSET/MONOSC VERSION 1.2 - DESIGN SUMMARY - 5/ 1/85 11.26.42.
MENU ITEM NO. 1 - SUMMARY

DESIGN SPEED, KT	27.95	LBP, FT	429.70
ENDURANCE SPEED, KT	20.00	BEAM (ON DWL), FT	50.55
ENDURANCE, NM	4500.	DEPTH (MIDSHIP), FT	38.42
MILITARY PAYLOAD, LTON	970.0	DRAFT (DWL), FT	18.96
CREW ACCOM	301.	SPACE MARGIN FAC	0.000
		HULL VOLUME, FT3	569205.
ALLOW PRIM STRESS, KSI	19.04	TOTAL SHIP VOL, FT3	685574.
MIDSHIP MOI, FT2-IN2	237408.		
		DESIGN DRAG, LBF	332251.
PROPELLER DIA, FT	16.21	ENDURANCE DRAG, LBF	101805.
NO PROP SHAFTS	2.		
DESIGN PROP RPM	140.0	LIGHTSHIP WT, LTON	4381.9
ENDURANCE PROP RPM	90.4	D+B WT MARGIN FAC	0.125
		USABLE FUEL WT, LTON	873.8
NO SS GEN	4.	FULL LOAD WT, LTON	5668.4
GEN KW, KW	1530.8	FULL LOAD KG, FT	22.11
TOTAL ELECT LOAD, KW	4133.1		
MAIN NO ENG	2.	NO ENG USED AT ENDURANCE	1.
MAIN CONT PWR AVAIL, HP	26257.	MAIN PWR MARGIN FAC	1.250
DESIGN CONT PWR REQ, HP	21006.	ENDURANCE CONT PWR REQ, HP	9902.

ASSET/MONOSC VERSION 1.2 - HULL GEOM MODULE - 5/ 1/85 11.27.52.

MENU ITEM NO. 1 - SUMMARY

HULL SIZE IND-CALC
HULL SHAPE IND-CALC

	INPUT HULL	OUTPUT HULL
LBP, FT	429.70	429.70
LBP/B	8.50	8.50
LBP/D	11.18	11.18
T/D	0.493	0.493
LCB/LBP	0.503	0.503
PRISMATIC COEF	0.600	0.600
MAX SECTION COEF	0.803	0.803

BEAM, FT	50.55	DISPLACEMENT, LTON	5668.6
DRAFT, FT	18.96	VOL OF DISPLACEMENT, FT3	198269.
DEPTH (MIDSHIP), FT	38.42	HULL VOLUME, FT3	569205.
LCB(FROM FP), FT	216.15	DECKHOUSE VOLUME, FT3	116369.
VCB(FROM BL), FT	12.20	TOTAL SHIP VOLUME, FT3	685574.
LCF(FROM FP), FT	231.12	TRANSVERSE KM, FT	27.11
AREA OF MAX AREA STA, FT2	769.5	LONGITUDINAL KM, FT	999.10
MAX AREA STA LOC FM FP,FT	198.80		
WATERPLANE AREA, FT2	17339.8	NUMBER INTERNAL DECKS	4
WETTED SURFACE, FT2	23893.2	NUMBER TRANS BKHDS	13

ASSET/MONOSC VERSION 1.2 - SPACE ANALYSIS - 5/ 1/85 11.28.48.

MENU ITEM NO. 1 - SUMMARY

MAIN ENG TYPE-GT	MACHY BOX VOL-CALC	UNIT COMMANDER-NONE
SEC ENG TYPE-NONE	REFER MACHY LOC-INSIDE	SONAR DOME-PRESENT
SS ENG TYPE-GT	FREQ CONV-NEW	

FULL LOAD WT, LTON	5668.4	NO. OFFICER ACC	29.
DKHS AVG DECK HT, FT	9.00	NO. CPO ACC	21.
HULL AVG DECK HT, FT	9.07	NO. CREW ACC	251.
PASSWAY MARGIN FAC	0.000	TOT ELECT SYS KW AVAIL	6123.
SPACE MARGIN FAC	0.000	TOT CONT HP AVAIL	52514.
HAB STANDARD FAC	0.000		

	AREA FT2		VOL FT3	
	PAYLOAD REQUIRED	TOTAL REQUIRED	TOTAL ACTUAL	TOTAL REQUIRED
DECKHOUSE	7904.	17036.	116369.	153325.
HULL	8250.	44185.	569205.	541482.
TOTAL	16154.	61221.	685574.	694807.

SSCS GROUP	AREA FT2	VOL FT3	PERCENT-VOL	VOL ADJ FT3
1. MISSION SUPPORT	17474.	157903.	22.7	0.
2. HUMAN SUPPORT	15681.	144661.	20.8	0.
3. SHIP SUPPORT	22031.	213901.	30.8	0.
4. SHIP MOBILITY SYSTEM	6035.	178342.	25.7	0.
5. UNASSIGNED	0.	0.	0.0	
TOTAL	61221.	694807.	100.0	0.

Note: In the deckheight variation study, the baseline and the variant had equal 'between structural deck' deckheights throughout the ship (8'6" for the baseline and 9'0" for the variant). The exception to this was the deck immediately below the weather deck (forward of the break) which for both the baseline and the variant had a deckheight two inches higher than the average. Thus the average hull deckheight shows up as slightly higher than the figure stated in the text(i.e. 9.07 vice 9.00). The two extra inches are consistent in the two DGASWFF versions and thus do not affect the analysis results. The variation of deckheights on a ship depending on the arrangements (high for electronics, medium for manned, low for normally unmanned) is an interesting future study in itself.

ASSET/MONOSC VERSION 1.2 - WEIGHT MODULE - 5/ 1/85 11.33.49.

MENU ITEM NO. 1 - SUMMARY

		W E I G H T		CG-FT		W G T A D J		
SWBS	G R O U P	LTON	PER CENT	VERT	LONG	LTON	VERT	LONG
100	HULL STRUCTURE	1370.0	24.2	24.4	210.1	-10.0	34.6	236.3
200	PROP PLANT	433.7	7.7	17.7	299.7	0.0	0.0	0.0
300	ELECT PLANT	256.1	4.5	23.9	244.9	0.0	0.0	0.0
400	COMM + SURVEIL	651.4	11.5	11.8	163.3	0.0	0.0	0.0
500	AUX SYSTEMS	650.4	11.5	24.2	236.3	0.0	0.0	0.0
600	OUTFIT + FURN	403.4	7.1	27.8	214.9	0.0	0.0	0.0
700	ARMAMENT	130.0	2.3	35.8	193.4	0.0	0.0	0.0
M11	D+B MARGINS	486.9	8.6	22.2	218.8			
	D+B KG MARGIN			2.8				
	L I G H T S H I P	4381.9	77.3	25.0	218.8	-10.0	34.6	236.3
F00	FULL LOADS	1286.5	22.7	12.3	211.7	0.0	0.0	0.0
F10	CREW + EFFECTS	33.9		28.1	202.0			
F20	MISS REL EXPEN	144.3		36.1	189.1			
F30	SHIPS STORES	42.9		21.1	232.0			
F40	FUELS + LUBRIC	1015.7		8.4	215.0			
F50	FRESH WATER	49.7		5.3				
F60	CARGO	0.0		0.0				
M24	FUTURE GROWTH	0.0		0.0	0.0			
	FULL LOAD WT	5668.4	100.0	22.1	217.2	-10.0	34.6	236.3

ASSET/MONOSC VERSION 1.2 - HYDROSTATIC ANALYSIS - 5/ 1/85 11.35.09.

MENU ITEM NO. 1 - SUMMARY

APPENDAGE IND-WITH
HYDROSTATIC IND-FULL LOAD

DISPLACEMENT, LTON	5668.43	MAX AREA STA LOC FM FP,FT	198.81
LCG LOC(+VE FWD MID), FT	-2.37	AREA AT MAX AREA STA, FT2	765.118
MIDSHIP DRAFT, FT	18.87	BEAM AT MAX AREA STA, FT	50.52
TRIM(+ BY STERN), FT	0.00	DRAFT AT MAX AREA STA, FT	18.87
SHIP KG, FT	22.11	BLOCK COEFFICIENT	0.481
SHIP LBP, FT	429.70	PRISMATIC COEFFICIENT	0.599
METACENTRIC HT(GM), FT	4.84	SECTIONAL AREA COEF	0.803
WATERPLANE AREA,FT2	17301.1	WATERLINE LENGTH, FT	429.64
WETTED SURF AREA, FT2	23833.7		

ASSET/MONOSC VERSION 1.2 - COST ANALYSIS - 5/ 1/85 11.35.54.

NOTE-THIS INTERIM MODULE PROVIDES GUIDANCE FOR DECISIONS REGARDING SHIP DESIGN TRADEOFFS AND COMPARATIVE EVALUATIONS. REQUESTS FOR ESTIMATES OF SHIP COSTS FOR BUDGETARY PURPOSES SHOULD BE DIRECTED TO NAVSEA.

DEFAULT VALUES WERE PROVIDED THE FOLLOWING PARAMETERS-

INFLATION RATE ARRAY	ANNUAL TRNG ORD COST	PAYLOAD FUEL RATE
ANNUAL OPERATING HRS	UNREP UNIT CAPACITY	UNREP UNIT COST
UNREP O+S COST	SHIP FUEL RATE	

MENU ITEM NO. 1 - SUMMARY

YEAR $	1985.	NO OF SHIPS ACQUIRED	30.
INFLATION ESCALATION FAC	1.433	SERVICE LIFE, YR	30.0
LEARNING RATE	0.970	ANNUAL OPERATING HRS	2500.0
FUEL COST, $/GAL	1.200	MILITARY P/L, LTON	970.0
PAYLOAD FUEL RATE, LTON/HR	0.33	LIGHTSHIP WT, LTON	4381.9
SHIP FUEL RATE, LTON/HR	3.88	FULL LOAD WT, LTON	5668.4

COST ITEM	COSTS(MILLIONS OF DOLLARS) TOT SHIP	+ PAYLOAD	= TOTAL
LEAD SHIP	671.4	307.9	979.3
FOLLOW SHIP	311.5	276.2	587.7
AVG ACQUISITION COST/SHIP(30 SHIPS)	285.4	277.3	562.6
LIFE CYCLE COST/SHIP(30 YEARS)			1710.9
TOTAL LIFE CYCLE COST(30 YEARS)			51326.2
DISCOUNTED LIFE CYCLE COST/SHIP**			86.9
DISCOUNTED TOTAL LIFE CYCLE COST**			2607.2

**DISCOUNTED AT 10 PERCENT

END

FILMED

1-86

DTIC