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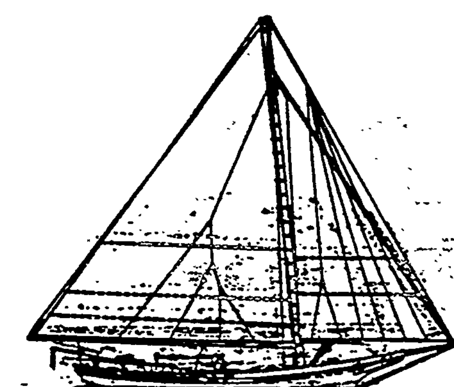

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No. 2

Producibility in U.S. Navy Ship Design

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ABSTRACT

Recent NAVSEA studies of a twin skeg hull form design applied to a T-AO type ship indicated many areas of possible improvement in producibility.

This paper reviews the findings of producibility studies and attempts to indicate specific areas where an improvement in producibility and attendant cost savings for Navy ships are possible without any degradation in ship performance and survivability.

Most available studies on producibility have an inherent trait of elaborating on details of shipyard producibility. This paper attempts to confine itself to the producibility aspect of the design phase, ending with the completion of contract design. While it is of course necessary for the Navy ship designer to know about producibility details of prospective building yards, he must be careful not to incorporate any details that may be restrictive on some of the prospective builders and thereby hinder competition.

Although the application of a twin skeg hull form to the ongoing T-AO program was determined by NAVSEA not to be practicable because of the advanced status of the ship acquisition program, it was determined that the concept of the producible, designed-to-build ship was worth further investigation for incorporation into future designs because of potential cost savings.

The paper concludes with recommendations for a method of application of producibility to the Navy ship design process for MSC-operated T-Ships.

INTRODUCTION

Producibility is defined as the capability to manufacture, build or assemble goods in a most cost-efficient manner. For this paper, producibility in the pure sense will have to be subdivided as required for the unique characteristics of naval ship design. The normal approach to the design of highly efficient details of construction cannot always be fully applied to naval ship design since the Navy's design activity stops at Contract Design completion, and it is not known at this point which of the prospective shipbuilders will be awarded the contract. The application of producibility to naval ship design is further complicated by the fact that there are usually fixed, and unchangeable mission requirements which are taboo and cannot be modified for any reason.

This paper examines which aspects of producibility are applicable equally to the range of prospective builders and can therefore be incorporated in a Navy ship design. The application of producibility is discussed in three segments: Feasibility Studies, Preliminary Design, and Contract Design.

PRODUCIBILITY FOR NAVAL SHIPS

Applying producibility to U.S. Navy ships is different than the application to commercial ship designs, considering that any Navy ship design must comply with the procurement methods and rules that have to be followed by government agencies. This means that the technical configuration and data in a bid package must permit all prospective builders to bid on the procurement in a fair and even competition. Maximum producibility would require a ship to be designed for construction in a specific predetermined production facility.

Producibility for Surface Combatants

A naval combatant's primary functions have priority over normal economy and producibility considerations in order not to degrade mission effectiveness. For example, high-speed small size and advanced naval surface combatants are usually weight sensitive and cannot normally tolerate the small weight increases associated with producibility considerations without a deterioration in their mission effectiveness. For these ships, it is, therefore, of the utmost importance to consider producibility and the attendant benefits and penalties during the earliest feasibility study phases. This approach minimizes performance decline and makes it possible to develop some general guidelines for the application of tempered producibility for these vessels.

Producibility for T-Ship Designs

T-ships are usually designed to commercial requirements with the exception of certain. "fenced" areas for mission-critical systems. These areas depend on the ship type and mission, and are usually invoked by very detailed specification language. T-ships are usually relatively slow speed vessels (20 knots or less) which are somewhat akin to comparable commercial vessels and are therefore not as sensitive to the slightly greater weight usually associated with a producible ship design. The Navy's damaged stability criteria, as applied to T-ships, not conducive to producibility due to limitations on compartment length.

Producibility in General

Primarily, this paper primarily investigates the application of producibility to commercial-like, "T-Ship design," since that is apparently the area where the most benefit may be obtained. To apply producibility, one must obviously first know the number of ships to be built, since the design effort expended to obtain a producible ship varies directly with the number of ships to be built. Only a minimal effort is justified when one ship is built from the design and a much larger effort can be made as the number of units to be built increases until the economy of scale curve levels off. The discussion of producibility is subdivided into Feasibility Studies, Preliminary Design, and Contract Design phases. The most benefit can be gained in the early feasibility stage and the least benefits are obtained in the later phase of Contract Design. The maximum effort must therefore be expended in the early design stages. In other words, the return for producibility efforts is **maximum in** the **beginning** of the design project and declines to a minimum as the design matures at the end of Contract Design. The return from producibility efforts increases again during the Detail Design effort due to shipyard appiied erection joints and details of assembly. A possible general approach to producibility in naval ship design would be:

1) determine the number of ships to be built;

2) determine the possible range of prospective U.S. shipbuilders and their individual production methodology and facilities; and

3) determine ship size and compartmentation by evaluating stability, mission requirements, and producibility considerations such as -frame spacing, plate thickness, and possible erection joint locations to suit all prospective builders.

PRODUCIBILITY IN NAVSEA

Background

The Naval Sea Systems Command (NAVSEA) has a long history of considering producibility in conjunction with ship design. For example, producibility improvement has been a serious concern in the design stages for the T-AO 187 and DDG 51. As recently as 1985, the NAVSEA Naval Architecture Subgroup (SEA 55W) proposed a Twin-Skeg Integrated-Hull design concept (2) (references are listed at the end of the paper) as an alternate ship design for the T-AO 187 program. This alternate design incorporated some unique hull form characteristics and certain design-to-build features. The producibility features considered were as follows:

- Maximized areas of flat plate.
- Maximized areas of single curvature, for remaining shell plating.
- Increased frame spacing and reduced numbers of piece parts in structural assembles.

- Standardized brackets and web frames, and use of bilge brackets in lieu of longitudinal stringers in the bilge turn area.
- Carefully arranged erection joints.

The intent of the Twin-Skeg Integrated Hull Design for the T-AO was to achieve procurement cost savings with an integrated hull form, basic arrangement, and structural configuration which were aimed at improved producibility. Simultaneously, the Twin-Skeg T-AO design provided equal (or better) ship performance and intact and damaged stability characteristics, relative to that achieved with the existing T-AO 187. The evaluations presented below emphasize the analyses of the producibility concepts which may affect the ship general naval architectural characteristics and performance, particularly in the areas of intact and damaged ship stability, and the producibility "lessons learned." The hydrodynamic performance of the Twin-Skeg T-AO design (including powering/fuel consumption, and seakeeping and maneuvering performance) is the subject of another paper (1) and is not discussed herein.

Twin-Skeg T-AO Design & General Description

The same general constraints and requirements that applied to the T-AO 187 were also applied to the Twin-Skeg T-AO hull. These constraints included general hull parameters, namely length, depth, draft, beam, speed/power, cargo capacity, deck arrangements, and major watertight subdivision. The Top Level Requirements (TLR) for the T-AO 187 was also applied to the Twin-Skeg T-AO configuration.

The T-AO 187 Class Fleet Oiler has been designed with the maximum utilization of commercial standards except for the following systems areas, which were subject to U.S. Navy design standards:

- UNREP
- Cargo Handling
- VERTRHP
- Degaussing
- Navy Communications
- Electrical Distribution Philosophy
- Steering Gear
- Nixie
- Helicopter Platform
- Helicopter Control Station

The application of the proposed alternate hull form to the -T-AO 187 Class Fleet Oiler program had to be accomplished in a relatively short time. To save time, NAVSEA decided to utilize the existing deckhouse, weatherdeck arrangements and UNREP arrangement, and concentrate efforts in the areas affected by the proposed alternate hull form.

DESIGN CONSTRAINTS

Hull Form Design and Appendages

The final hull form of the Twin-Skeg T-AO design was basically derived from the material presented in (3), with the addition of a NAVSEA-designed bulbous bow. The proposed Twin Skeg T-AO design has the following distinctive features when compared to the existing T-AO 187 design:

Maximum utilization of flat or single curvature plating, except for the bulbous bow and the twin skegs;

Twin side skegs, extending from near amidships to about station 19;

Two 26-foot diameter, slow turning (60 rpm) skewed propellers;

A large, Nabla-type bulbous bow;

A relatively large stem radius and soft shoulder;

A wave-knife stem;

Larger frame spacing;

Use of flat bars where possible in lieu of angles or tees.

The final version of the Proposed Twin-Skeg T-AO hull form is depicted in Figure 1, which compares the Twin-Skeg T-AO and the T-AO 187 body plans. Table 1 lists the principal characteristics of both hull types.

The Twin-Skeg T-AO design concept concentrates not only on the producibility aspect but also on the hydrodynamic performance (1). With respect to the producibility aspect, the Twin-Skeg T-AO hull form incorporates significant amounts of flat hull surface and single curvature shell plating. The producibility concept of the Twin-Skeg T-AO resulted in a fuller and flatter forebody

TABLE 1 COMPARISON OF HULL FORM CHARACTERISTICS
TWIN-SKEG T-AO VS. T-AO 187

	TWIN-SKEG T-AO	T-AO 187
LOA	675'-6"	6[illegible]'-6"
LBP	648'-0"	650'-0"
Beam, molded	97'-6"	9[illegible]'-6"
Draft, DWL	34'-6"	34'-6"
Displacement, DWL	41,073 LT	40,140 LT
C_b	0.656	0.643
C_p	0.669	0.655
C_x	0.981	0.982
LCB, aft of midship	1.11 FT	1.75 FT
LCF, aft of midship	28.58 FT	27.23 FT
Station of max. area	10.50	10.00
Wetted Surface	90,858 FT^2	78,870 FT^2

Note that all the above data is at the Design draft of 34 feet 6 inches (molded).

sectional area curve than the existing conventional T-AO 187. The sectional area curves of the T-AO 187 and Twin-Skeg T-AO are presented in Figure 2.

The second objective of the Twin-Skeg T-AO design was to develop a hull form with equal or better hydrodynamic performance at design speed compared to the existing T-AO 187 design. Therefore, the fuller forebody of the Twin-Skeg T-AO is traded for a softer shoulder than the T-AO 187. This trend is clearly shown in Figure 2, particularly from stations 5 to 10.

Usually, at high speed, the softer shoulder tends to reduce the forward shoulder wave. However, the fuller bow section will increase the bow wave size, negating any resistance reduction related to the forward shoulder wave. The original design was intended to have the

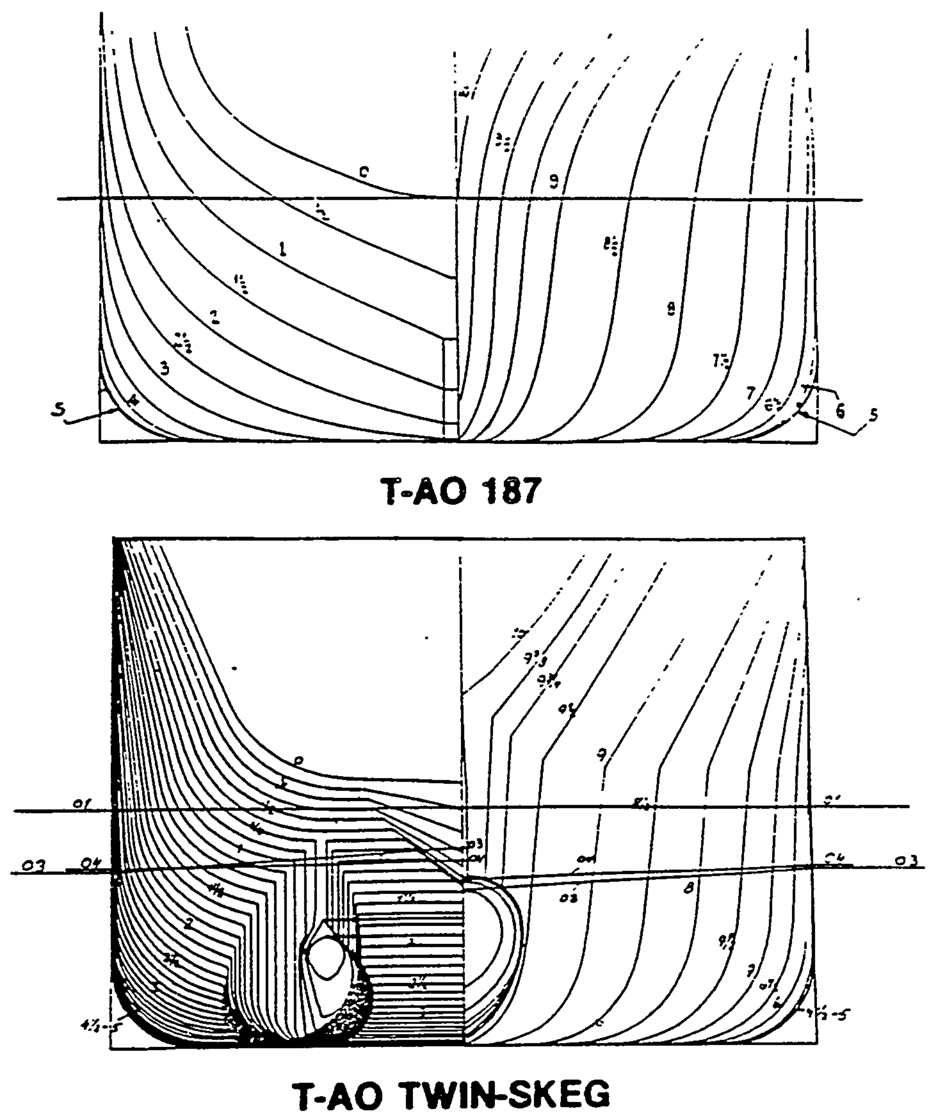
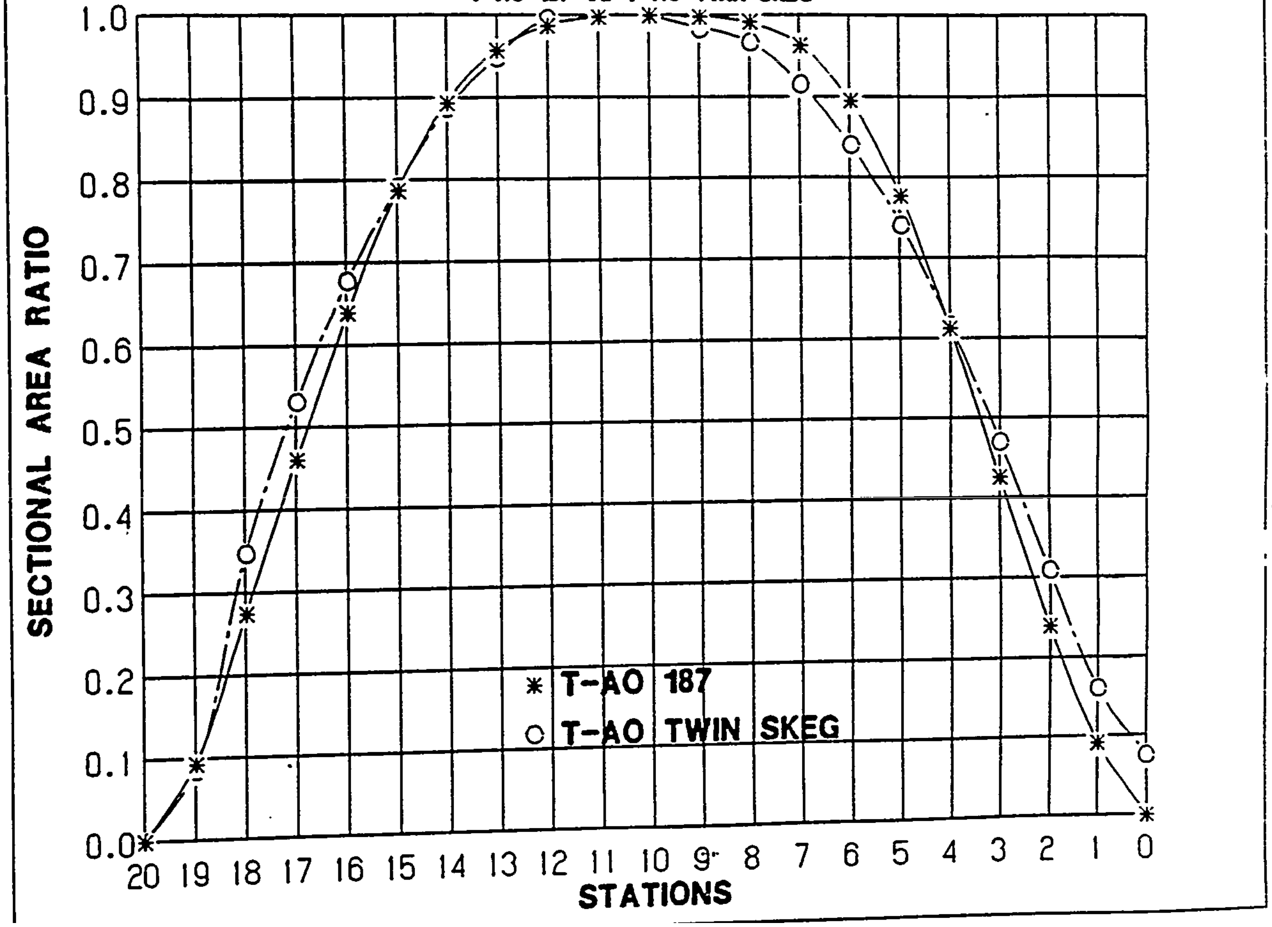


FIGURE 1 BODY PLANS

FIGURE 2 COMPARISON OF SECTIONAL AREAS
T-AO 187 VS T-AO TWIN SKEG



optimum hydrodynamic performance at design speed rather than at the speed at which the ship, according to the peacetime speed-time profile from the TLR, operates for the majority of its time (greater than 75 percent). In order to cancel the bow wave which is generated by the relatively blunt bow (note that the Twin-Skeg T-AO entrance half-angle is 16 degrees, whereas that of the T-AO 187 is 10 degrees), the original Twin-Skeg hull form was equipped with a relatively large bow bulb. This bulb resulted in a very good powering characteristic high speed but also a relatively high fuel consumption penalty at off design (ballast condition) drafts, particularly at low speed. Subsequently, the originally designed bow bulb was replaced with a smaller, NAVSEA-designed bulbous bow (l).

The original Twin-Skeg T-AO had a large Nabla (inverted triangle) type bulbous bow, with the top of the bulb at the design waterline. This bulb resulted in a significant fuel consumption penalty at off-design drafts, particularly at low speed (12 to 14 knots).

The final Twin-Skeg T-AO hull has a NAVSEA-designed bulbous bow which is optimized for the ballast condition, and the top of which is about 24 feet above baseline versus a 34 feet 6 inch design draft.

The Twin-Skeg T-AO hull form has more "flat plate" content. than the T-AO 187 and most of the Twin-Skeg T-AO curved shell" plates are single curvature. The forebody has a distinct knuckle line where the side shell plate changes from a near vertical lower hull into the bow-flare of the upper hull.

The Twin-Skeg T-AO hull has two large 26-foot diameter, four-bladed, skewed CRP propellers. The propeller shafts are supported and enclosed by two asymmetric side skegs extending from near amidships. These skegs are of substantial cross section and are designed as box girders, continuous through the shell in order to serve **as** propulsion machinery foundations. The skegs have planar outboard sides and bulbous inboard sides, and are shaped to create pre-swirl for the propellers. The skegs are toed in aft at an angle of 2.29 degrees with respect to the ship centerline.

At the extreme stern is a Vee-shaped centerline skeg. It functions primarily to protect the relatively flat bottom under the stern overhang from slamming damage. A more detailed description may be found in (l).

Two horn type rudders of relatively large size, with an area of about 395 square feet each, are fitted. These require a steering gear capable of producing a total of 18 million inch-pounds of torque to operate both rudders. By comparison the T-AO 187 has a rudder area of 295 square feet for each rudder and a steering gear capable of a total of 12 million inch-pounds of torque.

The forebody of the twin-skeg hull form consists of rather extreme U-shaped sections with nearly vertical sides, except for the small knuckle portion at the upper ends. The afterbody inboard of the skegs consists of straight line sections parallel to the baseline.

Structure

The structural configuration is intended to maximize producibility through the reduction of the number of piece parts. The web frame spacing of the Twin-Skeg T-AO is 14 feet 6 inches throughout the longitudinally framed cargo-area, vice 10 feet in the T-AO 187. The bow and stern areas are transversely framed, with 36-inch frame spacing compared to 24-inch spacing in the T-AO 187.

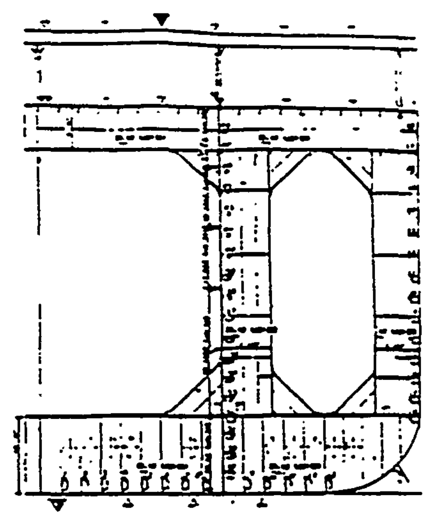
The depth of the floors and of the centerline vertical keel in the cargo area is 10 feet O inches in the Twin-Skeg T-AO, compared to 7 feet 6 inches and 4 feet 6 inches, respectively, in the T-AO 187. On the Twin-Skeg T-AO these members are fitted with a large face bar and form a level surface on which to land the upper hull structure modules.

There are no transverse struts fitted in the wing tanks. Deeper, slightly heavier web frame sections are used instead to reduce the number of structural pieces.

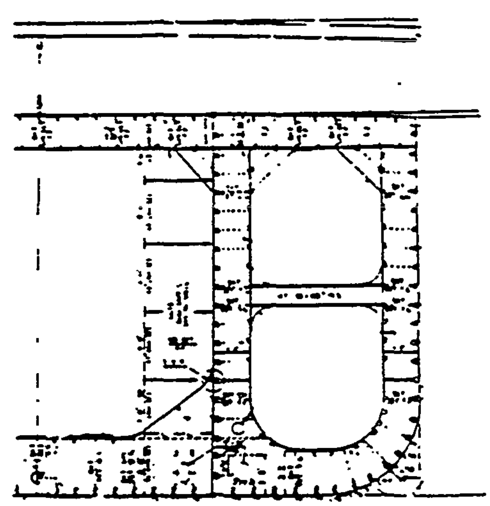
The bilge area has no longitudinal frames, resulting in relatively heavy, l-1/4-inch bilge plates to resist buckling. In lieu of longitudinal, bilge brackets, Figure 3, are fitted every 4 feet 10 inches. This results in two bilge brackets per side between every two web frames. Transition strakes are provided as appropriate to transition between the heavy bilge plating (1-1/4 inch) and the side and bottom shell plating thickness (5/8 inch).

Flat bar longitudinals are used at the main deck. At the side and bottom shell, and at the longitudinal bulkhead, longitudinal are angle sections all with 4-inch flanges, with only the depth of the web and weight varied to suit the location.

All effective longitudinal plating and members are of ABS grade higher strength steel AH-36 or AH-32, except the stringer and sheer strakes and the bilge strake, which are of more notch tough ES-36 to

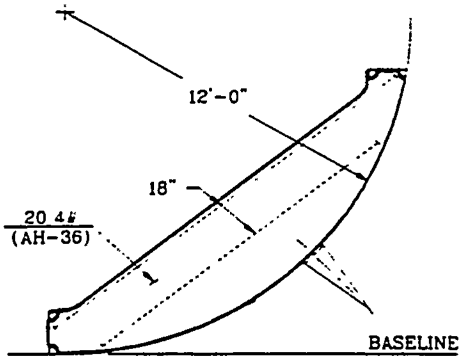


T-AO TWIN-SKEG



T-AO 187

FIGURE 3 MIDSHIP SECTION



SPACING 4'-10" (36 REQ)

FIGURE 4 BILGE BRACKET

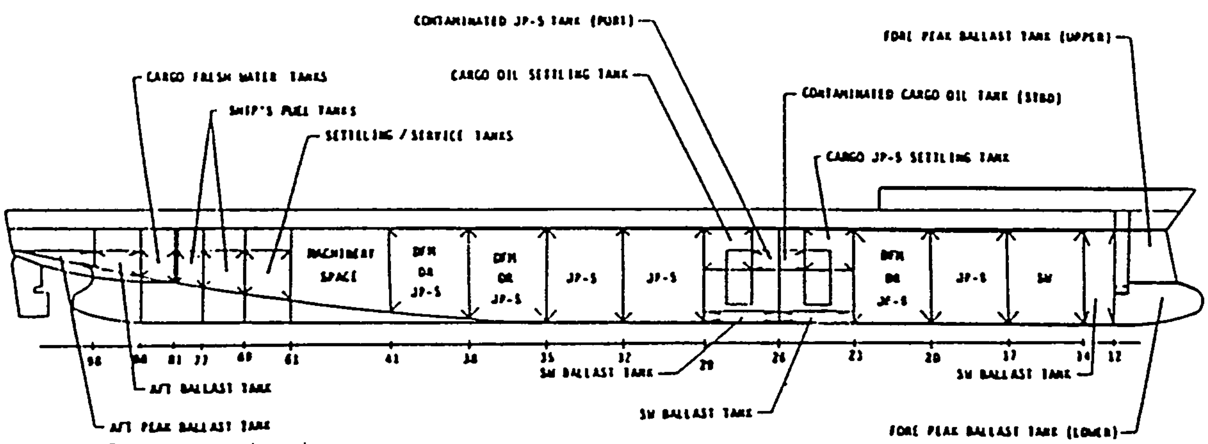
serve as crack arrestor strakes. The maximum permissible still water bending moment is 450,000 foot-tons, based on a calculated maximum still water bending moment of 434,561 foot-tons compared to the T-AO 187 with a permissible still water bending moment of 411,000 foot-tons based on a calculated maximum still water bending moment of 349,782 foot-tons.

The bulkhead spacing in the cargo tank area of the Twin-Skeg T-AO is 43 feet 6 inches, compared to 40 feet for the T-AO 187. This results in fewer bulkheads, and fewer web frames per compartment, although each individual web frame is somewhat heavier.

Figure 3 depicts the midship sections of the Twin-Skeg T-AO and, for comparison, the T-AO 187. Figure 4 shows the bilge bracket.

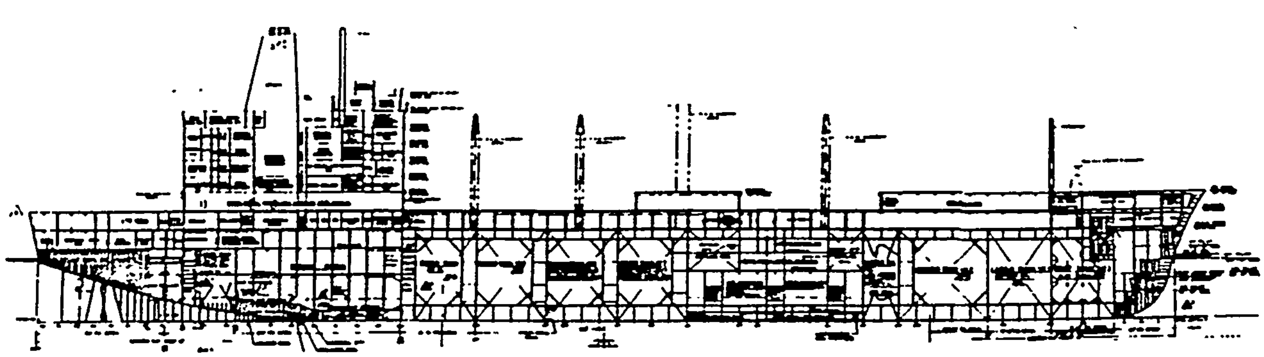
Compartmentation

The subdivision of the Twin-Skeg T-AO is determined by the desired cargo capacity, the necessary selectivity of product, the availability of segregated ballast to negate trim and minimize bending moment, and the damaged and intact stability requirements. The limitation of product outflow for IMO requirements is not a driving factor since the compartment/tank size required for stability and cargo flexibility is much smaller than the IMO tank size limitation for outflow (pollution) restriction.



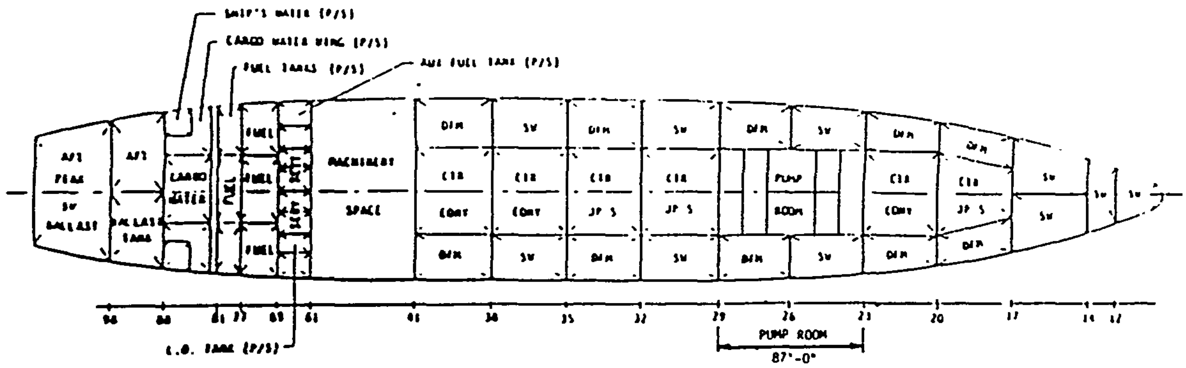
NOTE: Same superstructure as T-AO 187

T-AO TWIN-SKEG

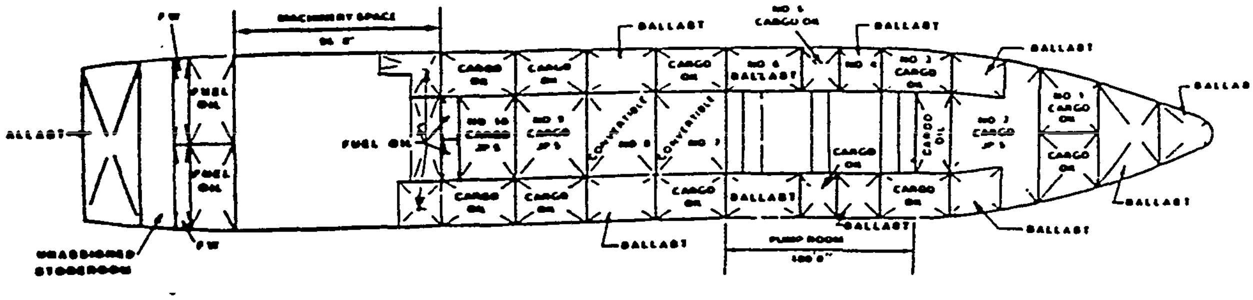


T-AO 187

FIGURE 5 INBOARD PROFILE



T-AO TWIN-SKEG



T-AO 187

FIGURE 6 TANK ARRANGEMENTS

The forepeak tank has been divided horizontally into an upper and lower peak tank at the top of the bulb. This prevents the otherwise overly large single forepeak tank from being filled completely and possibly over-stressing the hull girder in the process. The smaller forepeak tanks cannot overstress the hull. This is common practice on ships with relatively large bulbs and attendant large forepeaks.

The tank arrangement shown in Figures 5 and 6 is the result of the iterative design process involving damaged stability and structural strength analyses.

Cargo Pump Room

The cargo pump room on the Twin-Skeg T-AO is 87 feet 0 inches long from frame 23 to frame 29, in the center tank area, between the two main longitudinal bulkheads which are 23 feet 3 inches off centerline. The cargo pump room is divided into two segregated motor rooms and surrounded by the pump room, Figures 7 and 8. Outboard of the cargo pump room are two wing tanks each, port and starboard. Compared to this, the T-AO 187 has a 100-foot long cargo pump room which is divided into three segregated motor rooms, three pump rooms and two manifold rooms. Outboard of the cargo pump room are- three wing tanks each, port and starboard.

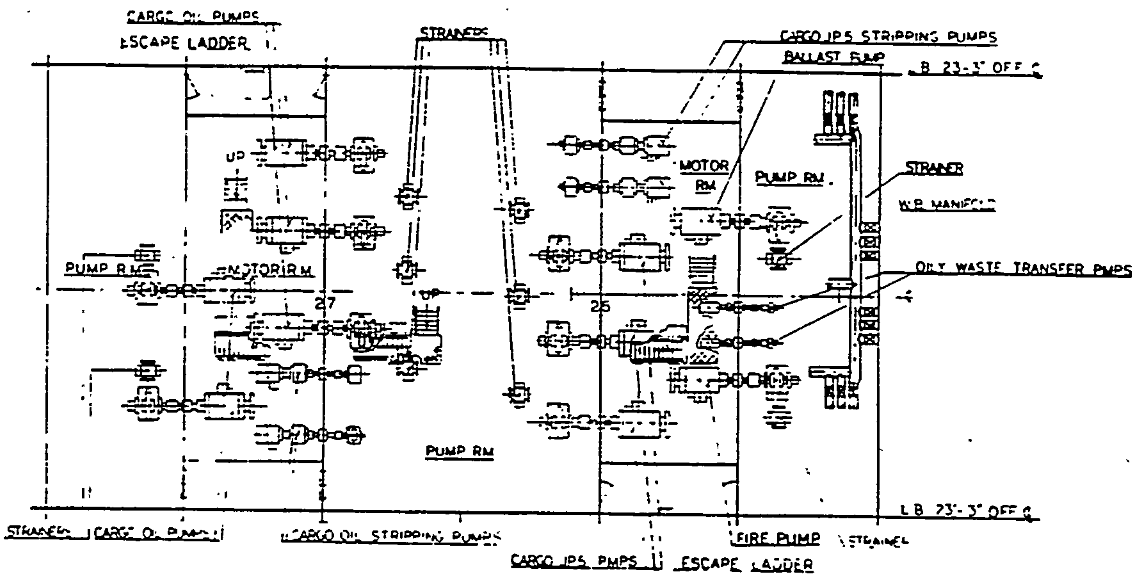
Machinery

The propulsion machinery plant is located in one machinery space, frame 41 to frame 61, and consists of two medium speed, ten-cylinder vee-type diesel engines. Each engine is capable of providing 16,500 BHP at 400 RPM.

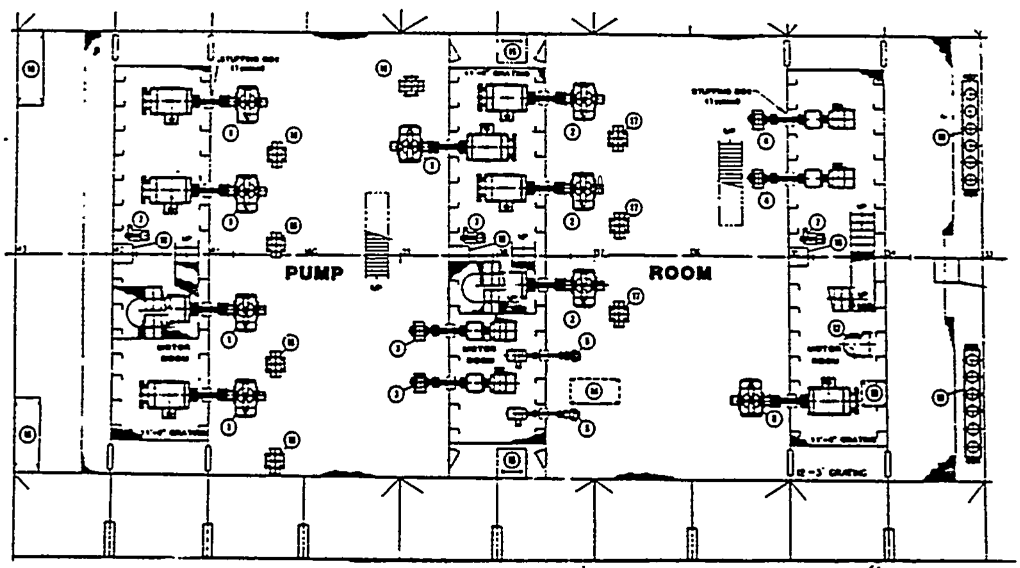
The propulsion plant is designed for unattended machinery space operation, with the ABS classification ACCU. The engine room extends vertically from the tank top up to the main deck. There are four general levels of equipment in the engine room, the tank top, the 14 foot, the 25 foot, and the 40 foot levels.

General Concept Evaluation

The Twin-Skeg T-AO structure had been designed according to the American Bureau of Shipping (ABS) Rules for Building and Classing Steal Vessels, 1987. The initial Twin-Skeg T-AO general arrangement and compartmentation had to be adapted to be similar to the configuration of the existing T-AO 187 Class Fleet Oiler so that the same mission



T-AO TWIN-SKEG



T-AO 187

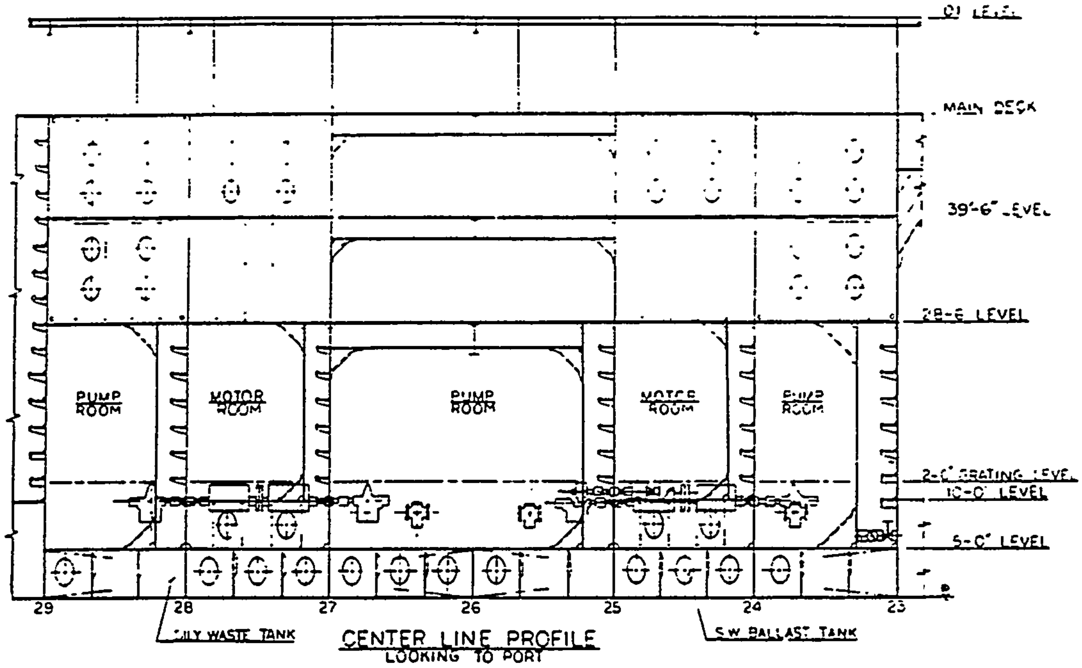
FIGURE 7 PUMP ROOM (PLAN)

requirements could be achieved. Therefore, the degree of freedom in the design of the Twin-Skeg T-AO design was significantly less than a new design would have been. Extensive concept evaluation, including detail weight estimates, longitudinal strength, and damaged stability analyses were performed for the Twin-Skeg T-AO. The final compartmentation of the Twin-Skeg T-AO evolved after six iterations of detail longitudinal strength and damaged stability analyses.

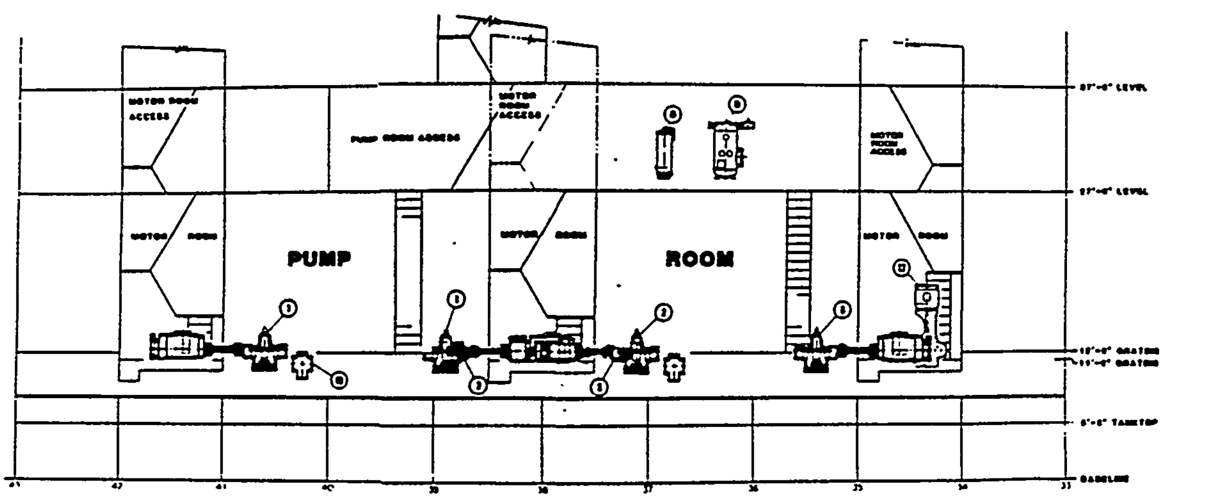
The overall objective of the Twin-Skeg T-AO was aimed at improved producibility with little or no degradation in hydrodynamic performance. The twin-skeg bulbous bow was therefore designed to offset any adverse hydrodynamic effect which might be imposed by the producible hull form. The overall hydrodynamic performance was found to be better than the existing T-AO 187 Class Fleet Oiler (l). Rowever, the twin-skeg did impose some design problems, particularly in the areas of damaged stability and longitudinal bending moment. Figures 2 and 9 display the sectional area curves and longitudinal weight distributions of the T-AO 187 and Twin-Skeg T-AO. The Twin-Skeg T-AO did possess more buoyancy than the existing

T-AO 187 from stations 15 to 18. However, the design configuration restricted the deck house location. Figure 9 clearly shows that the longitudinal weight distribution for the Twin-Skeg T-AO is significantly different from the T-AO 187. The effect, in terms of damaged stability for the longitudinal weight distribution increment, was found to be far more than the buoyancy increment from the twin-skeg. twin-skegs were also found to have some difficulties in counter flooding. The end products of this adverse effect caused by the skegs with respect to damaged stability was rectified by designinq a shorter machinery space for the Twin-Skeg T-AO .

The tunnel created by the twin-skeg configuration was not conducive to the development of a functional machinery arrangement within the reduced space since the hull is much shallower in the area of the machinery room. At midlength of the machinery space, the Twin-Skeg T-AO tank top is 11 feet above baseline

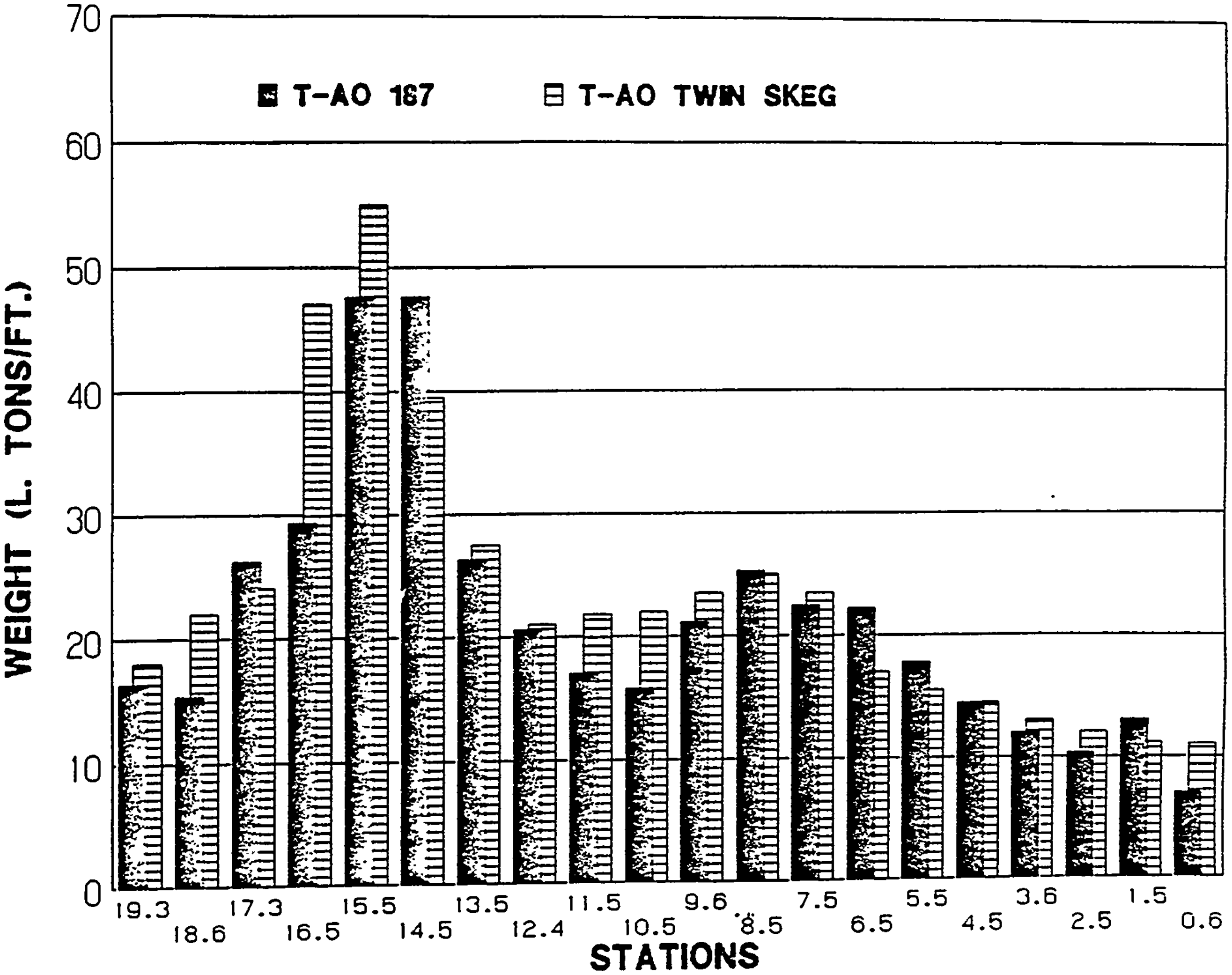


T-AO TWIN-SKEG



T-AO 187

FIGURE 8 PUMP ROOM (ELEVATION)



T-AO 187 VS T-AO TWIN SKEG

FIGURE 9 COMPARISON OF LONGITUDINAL WEIGHT DISTRIBUTION

between the skegs and 24 feet above baseline from the inboard side of the skegs to the ship side. In addition, the ship bottom between the skegs rises rapidly in the aft direction, dictating the 11 foot tank top height. In coinpazison, the T-AO 187 Class has a tank top 6 feet high. In effect, the T-AO 187 machinery space has one more useable level.

The final length of the Twin-Skeg T-AO machinery space was reduced to 60 feet to obtain satisfactory results for damaged stability. These machinery arrangement sketches were developed with the primary emphasis on fitting equipment into the space and only secondary emphasis on proper adjacency and access for maintenance. While the equipment was made to fit into the space available, it is not considered a satisfactory machinery arrangement by NAVSEA standards. If this were a completely new design, there would be greater flexibility to balance the conflicting requirements that drove the Twin-Skeg T-AO configuration. Therefore, an adequate machinery arrangement in a larger compartment could probably be developed, but this would require an additional analysis.

TWIN-SKEG T-AO PRODUCIBILITY EVALUATION

Producibility is systematic planned production, coordinating, and directing of all manufacturing activities and influences to ensure having goods designed and made in the most efficient procedure and configuration, on time, of adequate quality, and at the lowest practical cost.

As mentioned earlier, current U.S. Navy practice, any design for producibility must consider the procurement methods and rules that have to be followed by law. This in general means that the technical configuration and data in a bid package must permit all prospective builders to be able to bid on the procurement in a fair and even competition. This procedure may not always permit optimum producibility, which would require the ship to be designed to be built by a single shipyard. Maximum optimization of producibility is only possible by designing around a given production system/equipment, to the consequential exclusion or handicapping of others with slightly different production systems and equipment. For this reason, the T-AO 187 midship section drawing was made a Contract Guidance Drawing in lieu of the usual Contract Drawing. This allows prospective shipbuilders to optimize the ship structure to suit their particular production methodology and to adjust such details as longitudinal and web frame spacing for their individual panel lane characteristics. It also permits the trade-off of fewer, heavier piece parts versus additional weld passes, considering that fillet weld size is driven by the thickness of components to be joined.

The next consideration of producibility is the number of " ships to be built to a single design. The efforts expended on producibility will vary to an extent, depending upon the number of ships to be built.

The Twin-Skeg T-AO is a simplified, integrated and design-to-build hull with a structure designed for producibility, with specific details of construction. The web frame spacing is 14 feet 6 inches versus 10 feet O inches on the T-AO 187. This reduces the number of web frames in each compartment between subdivision bulkheads from three to two, but individual components and plating tend to be heavier since the distance between unsupported plating is larger. In 1986, NAVSEA performed a design study for the AO 177 Jumboization program which indicated savings of 44 LT (2.9 percent) in Group 1, and 4.1 percent of Group 1 labor, by changing from 9 feet to 12 feet web frame spacing in the plug, using standard NAVSEA structural design practice. There is also a smaller number of transverse bulkheads, longitudinal stiffeners and frames and floors. Table 2 provides a comparison of the number of piece parts required for certain components on the Twin-Skeg T-AO versus the T-AO 187.

The deliberate absence of longitudinal stiffeners in the bilge area reduces the number of piece parts but requires the bilge plate thickness to be l-1/4 inch, with appropriate transition strakes 11/16 inch thick, inboard and above the bilge plate to the normal 5/8 inch bottom and side shell thickness. The absence of longitudinal in the bilge area also requires two bilge brackets between each set of web frames, or six bilge brackets per side per compartment of 43 feet 6 inches. These bilge brackets are half-moon shaped with a flange along their top edge and a flat bar panel stiffener at mid bracket. The ends of this bracket are fitted against the longitudinal stiffeners at the top of and inboard of the bilge plate. These bilge brackets are depicted on Figure 4. The work content of these brackets will partially offset the gain from the deletion of the longitudinal stiffeners in the bilge area (as will the heavier bilge plating).

develop a construction (erection sequence) plan ahead of the actual design work is a prudent approach for the selected shipyard when planning a detail ship design. However, considering the Navy procurement system, to apply this construction plan, it must be designed to suit all prospective builders equally. This requires access to a current data base on shipyard facilities, including such information as maximum crane lift capacity, panel lane characteristics, and module or raft transport capabilities.

The original Twin-Skeg T-AO structural concepts contained a variety of construction details which, while certainly most suitable for producibility, exceed the amount of detail usually depicted on NAVSEA Contract and Contract Guidance drawings for T-ships.

The erection sequence plan for the Twin-Skeg T-AOI indicating unit break location, was also provided. The unit breaks indicated were based on ideally sized modules rather than considering the existing crane capacities of a prospective range of

TABLE 2

PRODUCIBILITY SAVINGS

ITEM	T-AO 187	TWIN SKEG	DIFFERENCE
DOUBLE CURVATURE PLATE	34%	10% EST	--
WEB FRAMES - NO.	30	18	-40%
WING TANK STRUTS - NO.	60	0	-100%
LONGITUDINALS - NO.	68	56	-18%
FRAMES & FLOORS - NO.	140	105	-25%
TRANSVERSE BULKHEADS - NO.	24	21	-17%
BILGE LONGITUDINALS - NO.	8	0	-100%
BILGE BRACKETS - NO.	0	36	+100%

shipbuilders. The crane capacity of the eleven U.S. shipyards capable of building Twin-Skeg T-AO size ships ranges from a low of four 40-LT capacity cranes to a high of one 1,200-LT crane over a building way, allowing a range modules for erection from 80/160 to a maximum of 1,200 LT.

Because of the attendant problem with the various size module requirements, it was decided not to indicate any unit breaks. But assumed unit break locations were considered in the development of the structural configurations. Uninterrupted sequence of erection was achieved" by assuring that no equipment is located across unit breaks which would prevent the pre-outfitting of modules in question.

Floors and bulkhead plating are installed up to a uniform height of 10 foot above baseline on the bottom shell. All these vertical plates mounted on the bottom shell are 'capped" with face bars presenting a level flat surface lower module on which to land the upper hull modules with relative ease.

Where knuckles occur in the shell or deck plating, they are located within a few inches of a deck or longitudinal bulkhead respectively. This location allows ease of construction; for example, it permits the slight lengthening of the end cut-away of stiffeners or webs to free the knuckle rather than perform another radius cut-away over the knuckle joint. The Twin-Skeg T-AO has fewer double curvature plates because of its simplified hull form. Table 2 gives a comparison. Single curvature plates are easier to construct and assemble since less fitting time is required.

The use of standardized parts of structure for Navy T-ship designs would require the prospective shipyards to agree on the use of the same standard structural details and parts. The Twin-Skeg T-AO is designed to maximize machine welding and to avoid, where practicable, structural configurations that would require manual welding and fit-up. This approach has advantages, but the details of how to accomplish this are shipyard specific. Navy designs must be developed to allow prospective bidders to pursue their most efficient methods of production.

To summarize the producibility of the design-to-build Twin-Skeg T-AO in the Navy procurement system, the following comments apply:

1. The design-to-build Twin-Skeg T-AO has distinct advantages in simplicity of construction, and its prospective application to a new design T-Ship can result in substantial cost savings due to the simplified hull shape, and to the simplified structural arrangement. Specifically, the Twin-Skeg T-AO structural concept features fewer, but heavier, harder to form pieces; minimized bending of plates and double curvature plates; longer frame spacing, and components serving more than one purpose, such as floor and foundation.

2. The design-to-build emphasis must begin in the Feasibility Study phase, where the designer should consider, based first on the ship parameters, the range of the prospective builders capabilities, and general producibility, considering the combined production characteristics of all builders. The producibility features incorporated here will have to be considered every time design changes are contemplated.

3. The emphasis on the design-to-build concept must continue through Preliminary and Contract Design. All appropriate sections of the ship specifications should have proper requirements assuring maximum consideration of producibility in the Detail Design process, which is normally performed by the builder.

CONCLUSIONS

The results of these studies indicate certain areas of possible improvements, particularly in producibility and hydrodynamics. The Twin-Skeg T-AO concept presents no unsolvable technical problems, although damaged stability is marginal. and machinery space arrangements are unacceptably tight with the current design constraints. If the degree of commonality with the T-AO 187 were relaxed, giving the designer more flexibility, the damaged stability characteristics could be improved. The concept of the producible, design-to-build ship is certainly worth further investigation for possible application to future high-speed naval auxiliary designs because of the potential for acquisition and life cycle cost savings.

This evaluation indicates that the producibility of future auxiliary ship designs can be improved upon by adopting longer frame spacings and simplified structural schemes to reduce the number of piece parts, and by minimizing hull curvature, especially double curvature plates. The potential improvements, however, would not be realized if these concepts were applied to an existing shipbuilding program. These concepts should be considered for new auxiliary ship designs, where weight sensitivity can be traded off against producibility, and where the design and program start-up costs would be applied only once.

RECOMMENDATIONS

Guidelines for the application of producibility should be developed, possibly subdivided into three phases -

1 Feasibility Studies

II Preliminary Design

III Contract Design

The following is an example of how producibility guidelines for T-ship design could read. Please note that this is only an example since the development of actual guidelines is well beyond the scope of this paper.

Phase I - Feasibility Studies

- Number of ships planned.
- Approximate ship characteristics.
  - Limiting drafts (air and water)
  - Limiting beam (PANMAX-St. Lawrence Seaway)
  - Limiting length
- Approximate power required for ship speed (step function in prime mover availability may require larger engine room).
- Lea.St curvature hull form compatible with speed requirement and seakeeping.
- Establish nonexclusive list of possible builders and prepare general guidelines based on these builder's capabilities.

  Module size and weight (maximum) for lift, turn and horizontal movement of modules.
- Establish data base on builder's facilities (most data exists with MARAD).

Phase II - Preliminary Design

- Do not use sheer.
- Use straight camber only where required for weather deck drainage.
- Establish common panel lane characteristics.
- Make midship section drawings Contract Guidance and require shipyards to submit their midship section for approval.
- Use flatbar stiffening wherever practical, if angles are used vary only the web depth and use same flange width throughout.
- Use as few variations in bar stock size as practical.
- Design configuration of structure with the fewest possible piece parts.
- Select the optimum (largest) frame and longitudinal spacing possible within the compartmentation required for stability.
- Leave production details, such collaring of stiffeners penetrating bulkheads or other plated boundaries generally undefined to permit the individual builders maximum use of their own methodology.
- Establish limiting plate thicknesses for availability and to avoid progressive weight gain (requirement for transition thickness plates to limit steps in plate thickness).
- Establish common weld pass steps based on plate/stiffener thickness, which is driven by stiffener/web spacing distance (i.e., plate./stiffener thickness at which welding would

require going from one to two weld passes).

- V-line boundaries should be established as early as practicable to allow the location of cable and pipe trunks within those boundaries prior to fixing the location of all spaces to be serviced by these cable or pipe trunks.

- Establish minimum number of different deck height dimensions for all levels throughout the ship.

- Minimize the number of different size and type closures, scuttles, and accesses through standardization. Standardize room/space sizes within arrangement constraints.

- Align and locate all **Sanitary** spaces to simplify piping.

- Generate parameters for combined module characteristics equally suitable to the range of candidate builders.

- Document the selected parameters for the design project at hand and require their use as guidelines throughout the design process.

Phase III - Contract Design

For ease of reading we have arranged the recommended general producibility guidelines for this phase by the SWBS category in which they most likely fall.

042 - General Administrative Requirements

To minimize the number of deviations and waivers, the specification should be written in a performance requirement format wherever possible to permit the prospective builder a maximum latitude in the equipment selection and system configuration design.

- Contract and Contract Guidance drawings should only depict the amount of details in construction that are required to assure satisfactory performance.

070 - General Requirements for Design and Construction

- Applicable bridge and canal clearances required should be clearly stated.

- Cofferdams and voids should only be used where absolutely necessary.

- By using a proper overall design approach, it is usually possible to colocate spaces of similar contents where the adjacency would not require cofferdams.

- Structural boundaries should serve more than one purpose whenever possible.

071 - Access

- The equipment module design needs to incorporate the special access requirements on Navy T-ships. This requires tempering the producibility aspect of a system design by considering damage control repair access requirements.

- Access openings should be designed so as not to be located on erection joints which would prohibit the preinstallation of access closures in all modules.

072 - Survivability

- Survivability requirements which, among other things, require the separation of crew accommodations are contrary to producibility but, of course, necessary. A compromise will have to be made between separation of crew and alignment/adjacency of similar function spaces.

077 - System Safety

- The application of producibility guidelines to ship systems normally has no impact on system safety; in fact, these producibility considerations enhance system safety as a byproduct (for example, cable trunks confine electrical fires and could be arranged for Halonon flooding).

100 - Hull Structure

- All guidelines enumerated under Phases I and II apply also to Phase III but will not be listed again.

- Minimize the number of piece parts.

- Optimize frame and web spacing against weight and number of weld passes.
- Depth of inner bottom must consider module size for lifting/handling
- Length of modules to suit steel availability.
- Consider pipe passages and piping system, flange or muff pipe joints at erection joints.
- Consider duct and cable passages in trunks to have fewer penetrations.
- Consider extent of transverse and/or longitudinal framing.
- Assure that the rudder support structure is segregated from the aft peak tank, so that the aft peak tank test does not depend on the rudder being in place.
- Align structure with equipment foundation requirements (one component - two functions).

200 - Propulsion Plant

- Prepare a preliminary list of candidate equipment.
- Establish functional groups for skid/module arrangement.
- Consider and select maintenance philosophy (change-out or repair in place) before determining connections, pipe joints, bolted plates and flanges.
- Use commercially available equipment without modification.
- Limit Navy type equipment to within the "fenced areas."
- Standard system modules should "be developed for the following:"
  - Fuel oil purifiers, pumps, and other components.
  - Lube oil purifiers, pumps, and other equipment.
  - Fire pumps.
  - Air compressors, denydrators, receivers, and other equipment.

    Distillers and fresh **water treatment system.**

The foregoing. examples of system modules are for illustration and not all inclusive.

300 - Electric Plant

- Diesel generator set modules
- Switchboard modules
- Consider adjacency of generator and switchboards (over/under, etc.)
- Assure switchboard is in relatively clean room and not in the engine room proper.
- Emergency genarator set module.
- Standardize electric motor/starter - pump, etc., skid modules to the maximum extent possible.
- Develop standard battery/battery charger and service modules.
- Develop standard M-G set skids & modules.

400 - Command and Surveillance

This group consists usually of "fenced" systems, and is composed of Government Furnished Equipment (GFE).

- Develop standard T-ship Navy communications room arrangement with a goal of a preoutfitted space module.

  This would permit more flexibility in scheduling the work on GFE.

500 - Auxiliary Systems

- Standardize pump skids and instrument boards.
- Standardize on the fewest practicable HVAC modules.
- Develop standard refrigeration modules.
- Modularize auxiliazy boiler and steam system.

° Standardize hydraulic systems (tank, pump, and controls).

600 - Outfit and Furnishings

° Deck houses should have flat sides and square corners.

° Develop arrangement with as many identical spaces as possible.

° Develop spaces with standard furniture arrangement within each rank group.

° Develop spaces to accept either whole or half panels of a commercially available marine sheathing.

° Align service (pipe, cable or duct) receiving spaces vertically.

700 - Armament

° Continue implementation of modular weapons system installations.

The foregoing, as stated previously, does not pretend to be all inclusive, but rather a guideline to possible areas of producibility application during the ship design process as it applies to T-ships. We realize that any one of the items listed could be the subject af a separate paper on producibility. We hope that this paper might motivate some thought in the direction of finding procedures to develop more producible Navy ship. designs in the future.

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