Modularization – A Tool For Production Friendly Ship Designs

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Ships are generally custom-built. Each ship is developed as per the owner's requirements independent of previous developed/designed hulls except in case of sister ships in which the same ship is repeatedly produced. Considering the varied uses and cost factors involved in the developments of such ships, it is not convenient to generate ship hulls as per the customer's requirement readily and often the development of such ship hulls is found to be time consuming and cost extensive process. Efforts have been made earlier to alter an existing design by making rather adhoc modifications to get a bigger ship or a ship with better performance in some respects. Examples are jumboising, changing the forward bulb shape or changing the propulsion plant. These modifications have not led to appreciable reduction in cost or time of construction.

This paper discusses the issue of modularisation of hull form and standardisation of complicated systems such that a large number of varied products can be made available satisfying owner's requirements. This effort requires to be made at the concept development stage itself with proper scientific investigations for optimal performance of all possible ships that can be generated.

Concept design of ships between 113m and 127m length have been developed using this modularisation principle and presented in [1] and [2]. The hydrodynamic studies relating to calm water resistance and wake characteristics due to stern shape have been presented in [3] and [4]. This hull form modulasation concept has also been patented by the authors. In this paper results of further numerical computations to justify modularisation are presented. Also discussed is the possibility of standardistaion of various systems in the ship such as propulsion system, steering system, anchoring and mooring system etc.

KEY WORDS
Modularisation; Ship Hull; Production kindliness; Ship Design

INTRODUCTION
International shipbuilding activity is a cyclic process. If the demand for ships rises, shipbuilding may not be in a position to supply the requirement. So there is a time lag for shipbuilding to increase production capacity to meet the demand. When demand for ships stabilises or reduces, the shipbuilding activity has to go through a process of recession and reduces the production capacity. At present, due to increased economic activity, shipbuilding industry is on a high growth path and all shipyards are flush with orders. But once the market need is reduced, shipyards will have to survive based on long term survival strategies. The bottom line of any such strategy is to provide quality ships at internationally competitive prices with quick delivery schedule.

One can, mathematically as well as realistically, optimise the production process if the product is to be mass produced and achieve full standardisation. Even this standardisation can lead to standardised operation and maintenance (and even, dismantling) process during the life of the product. The most common examples of such products are motor cycles and small passenger cars. However, ships are custom-built and efforts towards mass production of ships have cot succeeded [1]. For the shipbuilder it is necessary to build ships at a competitive price and time frame to capture the shipbuilding market. For the ship owner it is necessary to reduce the ship procurement time at a low capital (acquisition) cost to start getting returns quickly in an uncertain economic environment.

In a globally competitive market, if this can be achieved, it is win-win situation for both the builder and owner. The lifecycle of a ship can be broadly divided in two stages. The product realisation stage consists of two main processes – design and production, and takes time T_1 at the end of which the ship is delivered to the client. The second stage is the product utilisation stage which includes the processes of training the crew, commissioning, operation and maintenance of the vessel and finally, dismantling. The time take for this stage is much larger, say T_2. Fig. 1 shows this diagrammatically. If the total life of a ship is time T, then $T \approx T_1 + T_2$ there being a small overlap between T_1 and T_2 based on the training required for the operating personnel. If the product is a conventional ship, the training required is negligible and this could be high in case of a new ship type or ship having novel equipment. Time T_1 requires to be reduced for better commercial viability. Modularisation incorporating various standards of equipment, components and processes may be a way to achieve this objective.

The paper briefly discusses the design and production processes in shipbuilding and brings out various types of standardisations that can be incorporated. The paper argues that the hull shape itself can be made of number of standard modules which require to be developed at the design stage itself based on the shipbuilder's identified product mix.

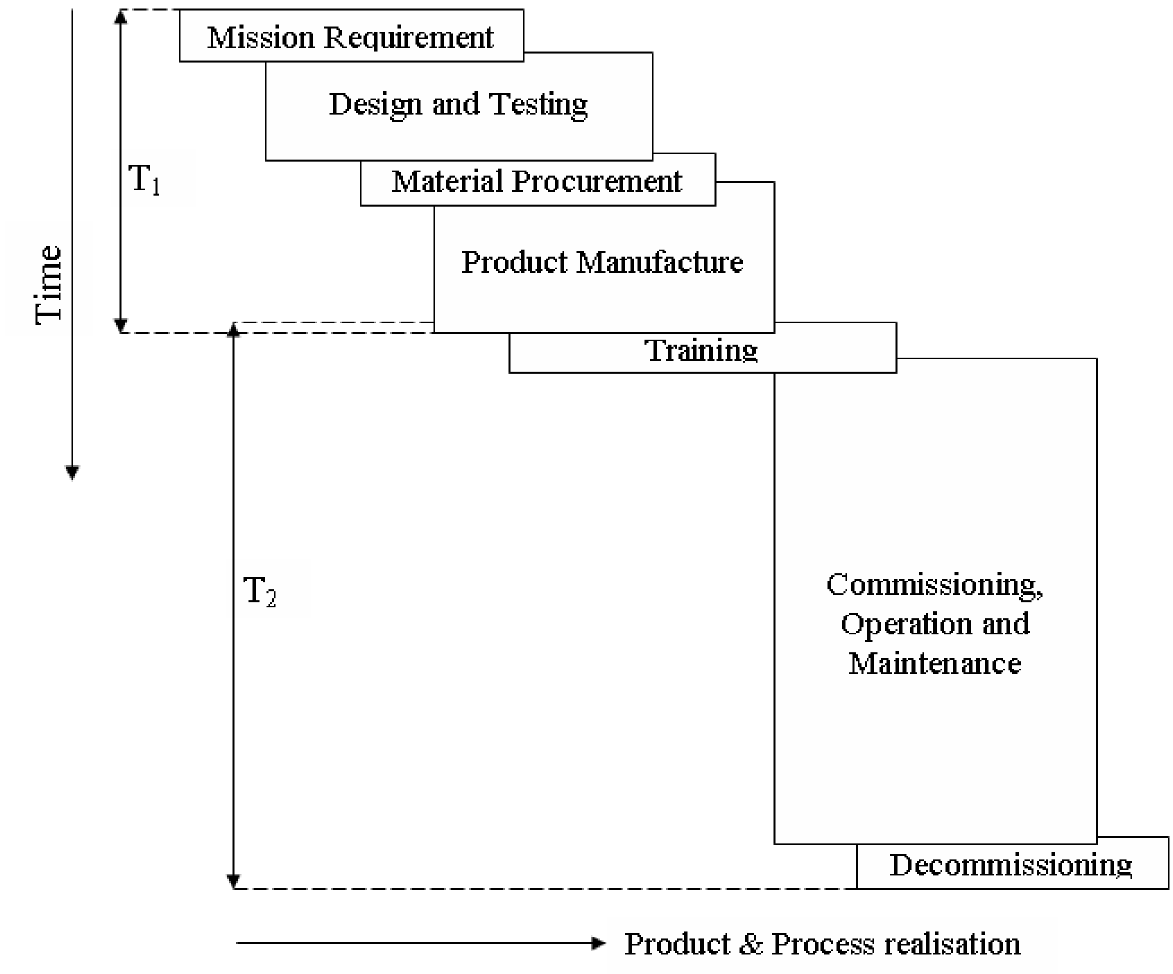


Fig. 1 Activities in Ship's Life Cycle

PRODUCT DEFINITION

Given a set of objectives, the process of designing a product must generate information about the product and at the end of the design process, complete information or knowledge about the product must be available. The information must contain instructions to manufacture the product, to operate the product and also to maintain the product during its life time. It is necessary to monitor the performance of the product in service to see the effectiveness of the designed product. Thus a life cycle modelling of the product is necessary starting from the initial stage of design itself. Any major engineering product works as a total system which may consist of a number of systems and sub-systems, each of which should be designed to serve its purpose. Further all systems and sub-systems must be integrated in such a manner that the product as a whole system works efficiently and effectively. Today no system works in isolation. It must necessarily interact with the world around it on issues involving technology, business, environment, society, law and such other items which may be technical, semi-technical or non-technical. The design must address these issues if the product is to succeed in the world of its operation. Fig. 2 gives different stages of the design process for a marine vessel. Tasks shown are common to all phases except that detailing in each phase may be different since information available at any stage may be different.

For completion of all tasks at different stages satisfactorily, there has to be a lot of communication between external parties (such as the owner, Classification Society, Regulatory authorities, vendors etc.) and internal groups in the ship design office and production facilities.

Mission Requirement
↓
Concept Design
↓
Preliminary Design
(Tendering)
↓
Contract Design
(Contract signing)
↓
↓
Detailed Design
↓

Manufacturing Design

Tasks in each phase of Design

Technical
- Hull form
- Arrangement
- Power
- Structure
- Equipment
- Space and volume
- Weight
- Stability
- Hydrodynamics

Economic
- Building cost
- Lifecycle cost

Manufacture
- Steel work procedure
- Assembly procedure
- Work content estimation
- Production information generation

Fig. 2 Design Phases and Tasks

During the design process there may be occasion to introduce design changes leading to design rework. One reason for change could be owner's preference (eg. accommodation arrangement), owner's speciality and changes in the market scenario (this could lead to major rework). Changes could also be introduced at different stages of design due to Classification societies and regulatory authorities for reasons of change of rules and recommendations or interpretation of rules. Production departments could affect design changes due to revised location of items, revised manufacturing process, revised material availability or even changes in capital facilities. Internal groups could also affect changes in the process of design development such as changing the engine or auxiliary item location at a later stage, changing equipment type and size at a later date or even changing structural layout. Reducing design time to a minimum is a necessary requirement in today's competitive environment. This leads not only to bid for a contract in short time but also it reduces rework due to quick design consolidation. This can be achieved by adopting concurrent engineering approach in ship design with adequate support for electronic communication and software. Further, standardisation of design process, of drawings and layouts, equipment and material can lead to detailed design development in quick time. In addition, if whole design modules of ship's specific geographical areas (such as stern, bow, midship area etc.) could be developed by which one could get different ships by adding different modules, design time can be drastically shortened. In this scenario, a detailed specification can be written in quick time such that the client or other external and internal groups would not be able to affect design changes.

The manufacturing process [1] in shipbuilding includes steel works erection and assembly of machinery, piping, outfit and electrical items. The work is quite varied in nature involving multiple skills and is generally labour intensive. In earlier days, a ship work breakdown structure (SWBS) was adopted for design as well as for production where ship works were broken down based on various systems such as steel works, machinery, outfitting etc. This method works very well for design where all the groups involved in design of various systems can work simultaneously to make the ship work as a total system. However, in production, this led to sequential activity, i.e., steel erection followed by machinery installation and outfitting and finally, painting. This also meant the skill of each worker was specified and he would be placed according to his skill in a particular job location. In this process, time taken for production was the sum of time taken for all individual systems. To overcome this problem, advanced outfitting techniques were adopted where some amount of outfitting was done during erection of steel subassemblies and assemblies. This led to product oriented work breakdown structure (PWBS). In this structure ship could be broken down (for production purposes) into assemblies or blocks which would include different production activities in that block. Here the worker could have a major skill along with some skill in related works. For example, a welder could also do some fitting and plumbing work and an electrician could also do a bit of welding. To adopt PWBS effectively, a ship break down into smaller work packages is necessary using a top-down approach. In this method, a ship is first broken down to zones based on geographical location and work complexity, example of such zones being stern, bow, cargo zone or accommodation. A zone could then be broken down to blocks. A block could consist of a number of smaller units called assemblies. One could further break it down to sub-assemblies to be fabricated from rolled plates and sections. Structurally it is easy to conceive a production system where sub-assemblies are joined together to form assemblies and then blocks. Blocks could directly be erected on the building berth or, could be made into modules on the basis of zones and then joined to form the whole ship. Similarly, outfit (or machinery, piping, electrical) works can be made into small units based on the block where it would be located and then on-block outfitting can be done by erecting these units on blocks before the block travels to berth for erection. The remaining outfitting work can be on-berth work. Fig. 3 shows the top-down approach of ship production using PWBS technique. The success of this system is based on adopting the concept of group technology. In group technology, the goal is to achieve repeatability of a manufacturing situation by characterising one-of-a-kind products. In this process it is possible to develop standard building blocks that can be combined to give very different final products.

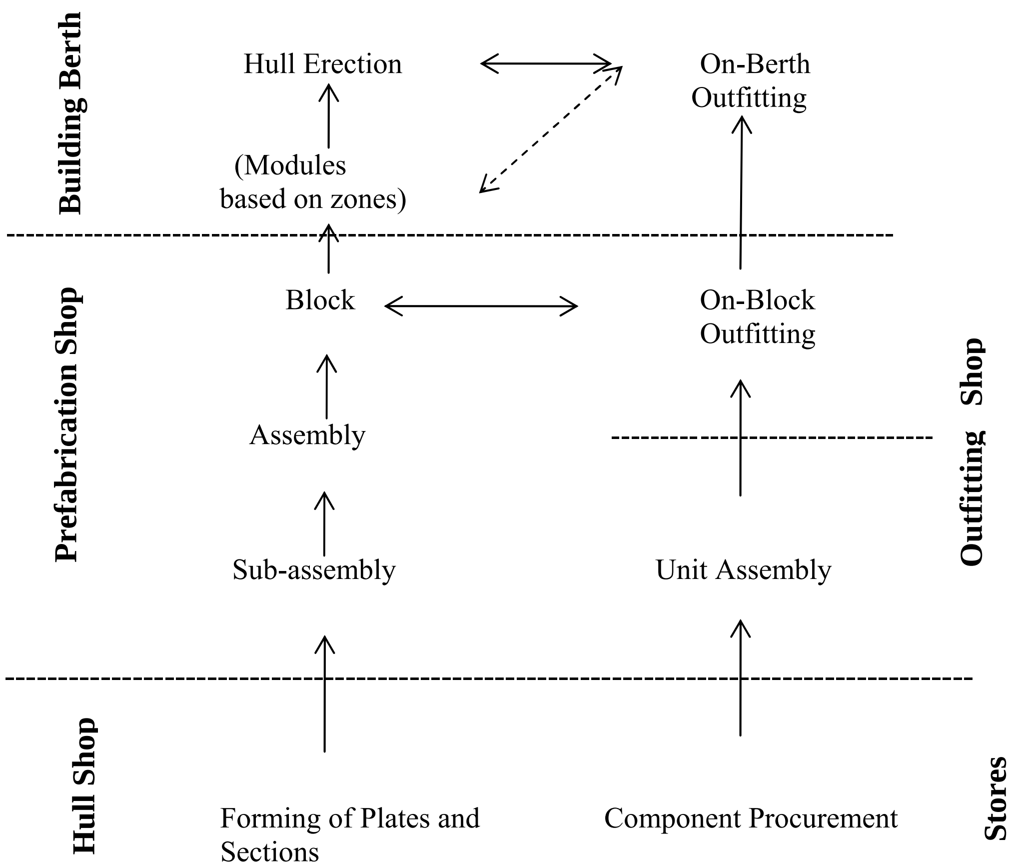


Fig.3 Modern Ship Production Levels

A stable production process depends on capital facilities in the shipbuilding yard, manning standards and a factor encompassing all other variables such as inventory, complexity of structure etc. Based on capital facilities and the layout of these, a PWBS can be worked out for a particular ship and accordingly production scheduling can be made. Labour productivity depends on a number of factors. The number of sister ships to be constructed has an important bearing on labour productivity. Whereas there could be mistakes leading to rework in the initial ships, this reduces considerable in subsequent ships and further, familiarisation with the production process leads to better productivity. Similarly, if specific works could be standardised, familiarity of the work should lead to increased productivity. If a whole block could be standard module, familiarity should further reduce block fabrication time. If the workers have good skill training, productivity is high. On the other hand, low skill levels may lead to rework. Multi-skill training is an important part of group technology concept. There is always an optimum number of workers (having adequate skill) to do particular job. If the worker strength is less, there is increased demand on each worker leading to stress and mistakes and therefore, rework. On the other hand, if the worker strength is more than optimum, there is overcrowding and lack of work efficiency reducing overall production efficiency. If the entire shipyard has to work efficiently it is therefore necessary that all workers must be engaged optimally at all times. Therefore, it is necessary to have a full (as per pre-determined product-mix) order book at all times.

STANDARDS AND MODULES

Standards are generally components, products or processes having the same specifications which are repeated again and again for some use. Stanrdisation is the process of creating standards. In shipbuilding, standards can be hardware items or processes. Raw material can be standardised in a shipyard, for example, steel plates and rolled sections such that the yard acquires plates and sections of certain specifications only which can be used to make different ships. Standards can also be of equipment and fittings and fixtures. Standard components can be used to make different units or blocks. Design standards include drawing standards, i.e., such as standard drawings for welding, of seatings etc. similar to *macros* in CAD work. Various manuals produced in drawing offices for production, operation and maintenance can also have a standard format. Engineering standards are standards for manufacturing processes such as procedures for doing particular jobs, may these be manufacturing or assembly. Jigs and fixtures for production may also be standardised so that these could be used for a wide variety of blocks. Creating standards for a shipbuilding organisation is a difficult process which includes study of detailed requirements of all ships in the product-mix identified by the shipyard for a few years. Standards, once set, should be followed rigorously to avail of the maximum benefit in terms of productivity. Of course, it may incur small sacrifices in performance level at sub-system and system level. Standards should change after a few years to take into account changes in technology and market demand.

In shipbuilding, at design/ production planning stage, ships are normally broken down right up to sub-assemblies and the work content of hull shop, prefabrication bay and berth are identified. Where forming of plates and sections is done in hull shop, sub-assemblies up to bigger units called blocks are made in the prefabrication bay. Modules (on the basis of zones) refer to large structural unit including machinery and outfit items so that it is complete in all respects. Group technology concepts can be incorporated at the assembly level construction based on structural similarities whereas at block and module level, group technology concepts will include outfitting works as well. For example, a structural assembly unit can be subcontracted out to a party doing ship structural works only where it can be produced efficiently. On the other hand, a fully complete module could be built in the shipyard using advanced outfitting techniques by pulling in workers of different skills to the same location where such work can be repeated again and again to give different modules based on ships built. It can very well be imagined that the convenience of construction of modules would greatly increase if the components used are standardised. The ultimate production efficiency can be achieved if the module as a whole (or, even large block) is standardised, i.e., it can be a part of a large number of ships built in the shipyard. Typical examples can be sister ships, the stern module of ships having the same engine room layout or the steering flat block where the steering arrangement is standardised.

In a ship most complicated parts structurally are the bow and stern which have three dimensional curvatures and large number of structural components. Further stern is the area where maximum amount of machinery and auxiliaries are installed and outfitting work is done including accommodation. The area of the ship between the stern and the bow, commonly known as the midship or cargo area, has the largest percentage of steel weight, but is structurally simple and can be broken into simple structural blocks to be manufactured conveniently. If the hull shape could be broken into modules and the modules could then be in two or three different standards (shapes), it would be possible to generate ships of different types and sizes, within limited range, by joining different shape modules. An attempt has been made to modularise the ship hull form by the authors and has been applied to generate different ship types and sizes and have been reported in references [2, 3, 4, 5]. The summary of that development is described in the next section.

MODULARISATION OF SHIP HULL

A ship is a complex three-dimensional structure the shape of which can be divided into a number of horizontal and vertical zones and shape of each zone could be designed based on its performance requirement and their could be some limitations and constraints in designing each portion such that combining all, one should get a complete and smooth ship hull. As an example, a ship hull could be divided into three zones longitudinally: aft body, mid body and fore body. It is possible to design each zone separately based on its functional and geometric requirements. The functional and geometric requirements of each zone can be stipulated very briefly as given in Table 1.

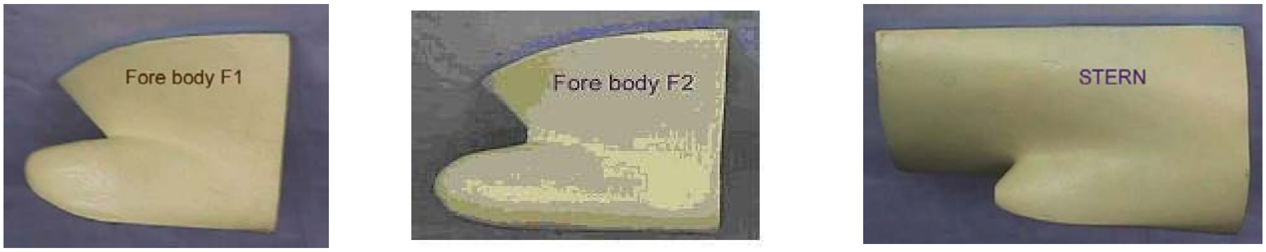
Table 1 Requirements of aft body, mid body and fore body of a ship

Region/Zone	Requirements	
	Functions	**Geometry**
Aft body	1. Hydrodynamics 2. Propulsion 3. Steering 4. Accommodation	Main dimensions Deck area C_B and *LCB* location *Smooth merging of the three zones*
Mid body	1. Cargo 2. Cargo volume 3. Production kindliness	
Fore body	1. Hydrodynamic 2. Production kindliness	

Table 2. Different Ship Forms generated from fore, aft and mid ship modules

Sl. No	Model Name	Fore Body shape	Mid Body Shape	Bilge Radius (m)	Length (m)	Breadth (m)	Ship Type
1	SM11F1	F1	M11	2.2	113.0	19/20.0	container
2	SM12F1	F1	M12	2.2	120.0	19/20.0	container
3	SM13F1	F1	M13	2.2	127.0	19/20.0	container
4	SM21F1	F1	M21	3.5	113.0	19/20.0	container
5	SM22F1	F1	M22	3.5	120.0	19/20.0	container
6	SM23F1	F1	M23	3.5	127.0	19/20.0	container
7	SM11F2	F2	M11	2.2	113.0	19.0	tanker / bulk carrier
8	SM12F2	F2	M12	2.2	120.0	19.0	tanker / bulk carrier
9	SM131F2	F2	M13	2.2	127.0	19.0	tanker / bulk carrier
10	SM21F2	F2	M21	3.5	113.0	19.0	tanker / bulk carrier
11	SM22F2	F2	M22	3.5	120.0	19.0	tanker / bulk carrier
12	SM23F2	F2	M23	3.5	127.0	19.0	tanker / bulk carrier

Using this concept, modules of two fore bodies (F1 and F2) and two mid bodies (M1 and M2) and one stern (S) were generated. Three ship lengths were generated in each combination by elongation of parallel middle body. Thus there were a total of twelve forms. The two mid body modules were generated by varying the bilge radius, i.e., one with 2.2m (M1) and the other, 3.5m (M2). This has been done by adjusting prismatic coefficient and keeping the block coefficient constant. Thus M2 has a longer parallel middle body and more pronounced forward and aft shoulders compared to M1. Each midbody module was further made into three modules each by elongating the midship length (M11, M12, M13 and M21, M22, M23). Thus a total of 12 forms could be generated (Table 2) using these modules, 6 feeder container vessel forms with 6.6m draught and 6 multipurpose vessel/ bulk carrier/ tanker forms with higher draught of 7.3 to 7.8m. Two accommodation modules were also designed suitable for various types of vessels. The hydrodynamic behaviour of all the forms, confirmed by tank testing have been presented in *[PRADS and MAHY]*. Fig. 4 shows scale models of two fore bodies and single aft body module. Fig. 5 shows two accommodation modules. Fig.6 shows three of the 12 ship forms generated by mating various modules. Fig. 7 shows the conceptual general arrangement of three vessels: a container vessel, a multipurpose cargo ship and a tanker.



Tanker Fore body Container ship fore body Common Stern

Fig. 4. Two fore body and one aft body modules

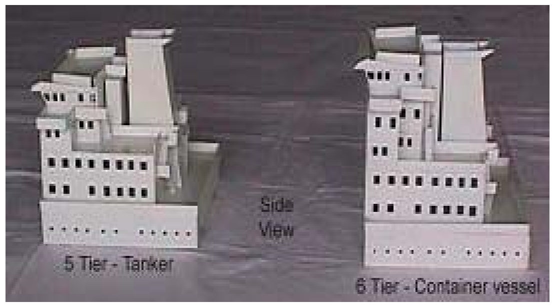


Fig. 5. Two Accommodation modules

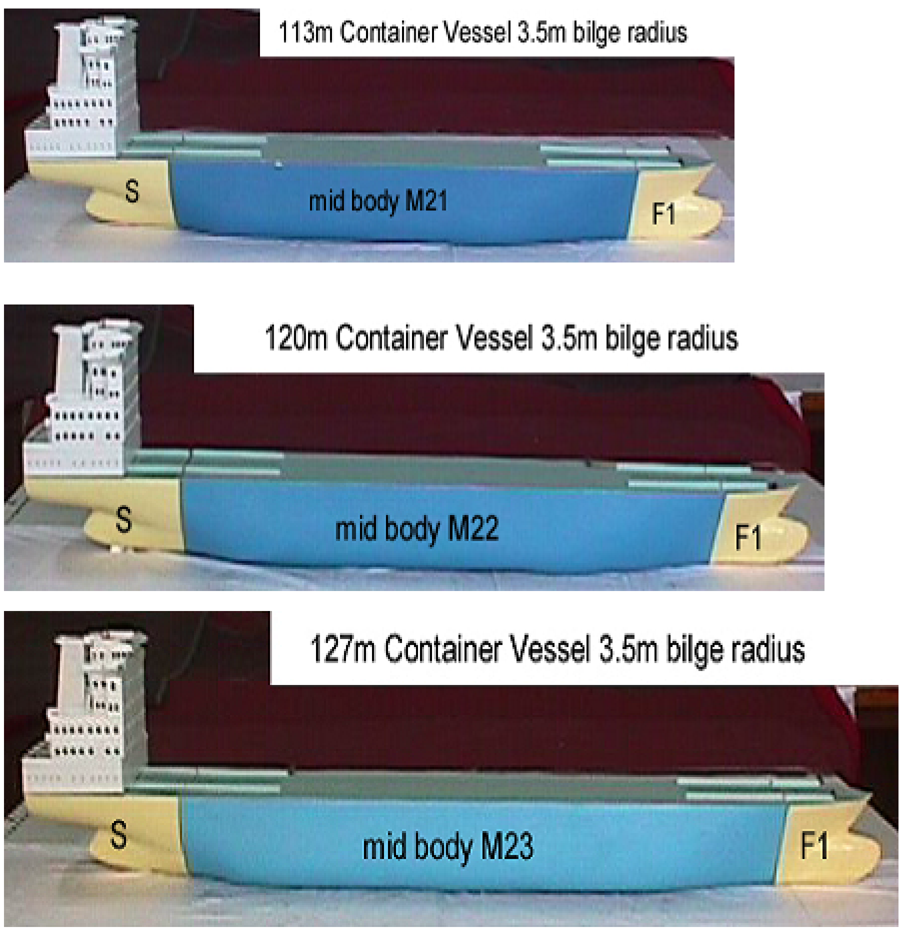


Fig. 6. Three of the 12 ship forms generated out of the hull modules

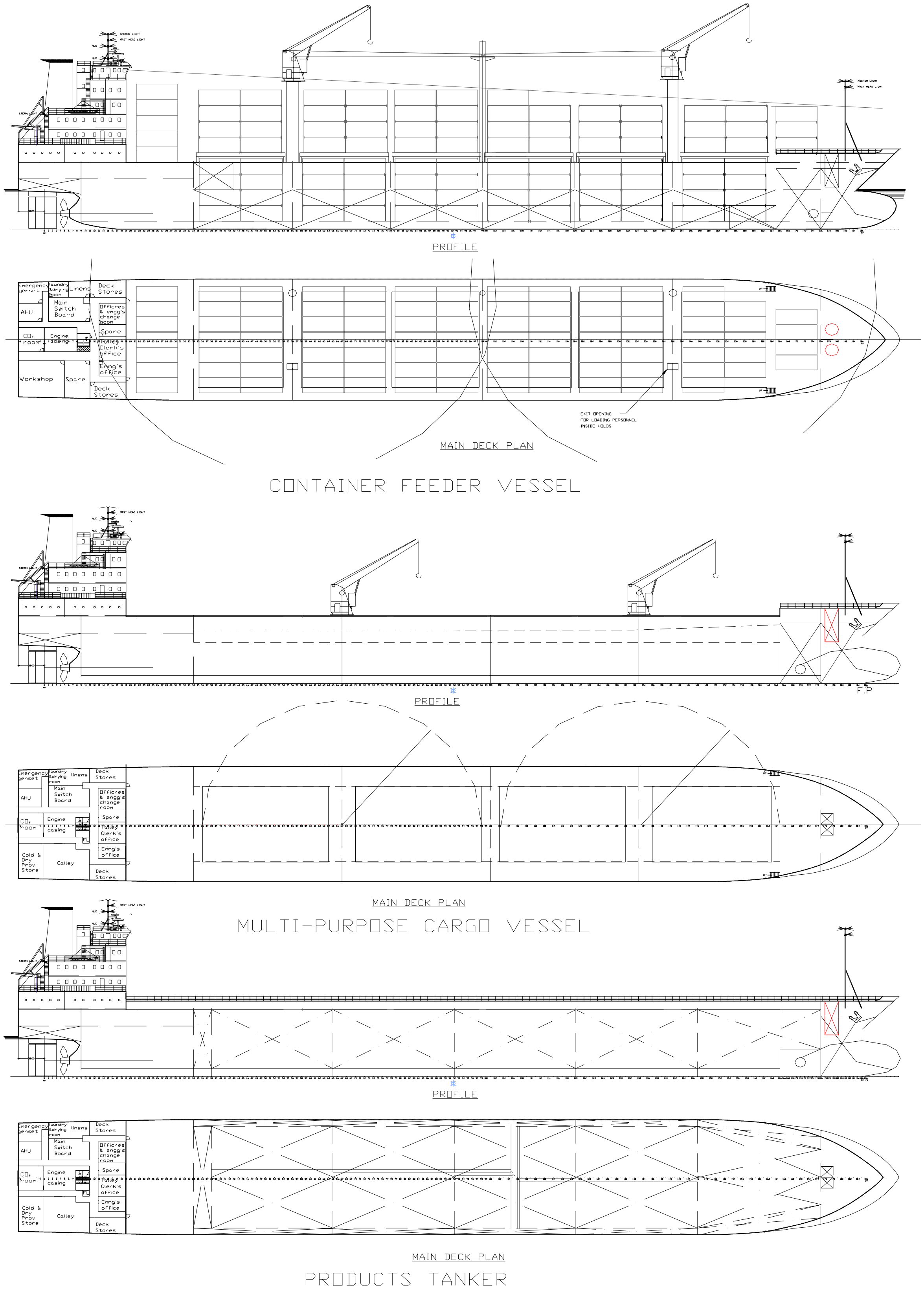


Fig. 7. Conceptual General Arrangement Drawings of three types of Vessels made from the Hull Modules

The advantages of hull shape modularisation are enormous. The production (engineering process) of the complicated shapes of stern and bow and also the simpler midship portions can be standardised. The systems inside these portions can also be standardised leading to components, fittings and fixtures standardisation. Rework can be reduced considerably. But all this is possible only if the shipyard builds ships confirming to these modules. So a pre-requisite to adoption of this modularisation concept is to have an identified product mix projection for the shipyard which should confirm to vessels built from these modules. This requires marketing effort suiting to these needs.

CONCLUSION

The paper discusses briefly the product (ship) realisation process which includes both design and production. The advantages of standardisation and modularisation in ship design and ship production have been highlighted. The paper argues that incorporation of standardisation and modularisation can lead to reduction in cost and time required for ship production. Ships are normally custom-built and standardisation of whole ship is not possible. However standard modules can be designed which can be incorporated in many different ship types reducing the cost and time of production. The authors have proposed modularisation of the hull form itself: an aft body module, a fore body module and a mid ship module. Each of these modules can have one or more standard designs and connecting different modules one can generate hull forms of different ship types and sizes. The example given illustrates 12 ships generated from two fore body modules, a common stern module and two mid ship modules. However, hull modularisation can lead to substantial reduction in time and cost only if production is coupled with a vigorous marketing effort to capture orders for these ship types so that maximum advantage of modularisation and standardisation can take place.

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