Both frame/plate and plate/plate connections are easier to weld than in curved contours, Takeda et al. (44). Furthermore, straight sections eliminates bending. Repetition of frames reduces the number of different parts, which have to be manufactured, tracked, assembled and installed,

- *chines and knuckles* necessary to achieve a less complicated curvature should be located at unit breaks. Do not place chines or knuckles either at or between bulkheads and decks, but 20 cm to 30 cm from the bulkheads or decks where the breaks will be made. Chines or knuckles above the waterline do not influence the hydrodynamic performance! However, the fatigue strength of the knuckles should be investigated. A large number of chines or knuckles may lead to problems in fitting during assembly and in fatigue strength, and
- establish *unit breaks* early in the design process and locate them for repetitive design and construction of the units. The location of the unit breaks can be critical to cost reduction. For some ships, such as tankers and bulk carriers, much of the structure is repetitive. By careful location of the unit breaks, the units to be fabricated can be built from one set of plans with resultant savings in engineering and production man-hours. This not only allows for assembly-line type construction with the cost benefits of line production, but also reduces the man-hours required to design the ship. The early location of unit breaks provides another benefit by permitting the designer to locate the various items of machinery and equipment in positions which facilitate unit outfitting. Any equipment which happens to be located across a break cannot be installed until after the units have been erected which makes it more costly. Joining the shell of two units is easier if the joint in one direction is stiff (near transverse structure, for example, deck or bulkhead) and the other is flexible (distant from rigid transverse structure).

The surfaces of modern hull geometries feature over wide areas a very small value for the smaller of the two principal curvatures. That is, the surface is almost developable and most plates can be cold formed. Only small changes in the hull form may be required to give developable hulls as proposed by Schenzle (35) (Figure 14.20). This would then have various positive effects on producibility:

- straight plate intersections reducing cutting work,
- increased in-plane welding suitable for robots, and
- straight stiffeners reducing forming work for stiffeners.

Especially the intermediate areas between flat regions in bottom and sides to the ship ends can benefit from such

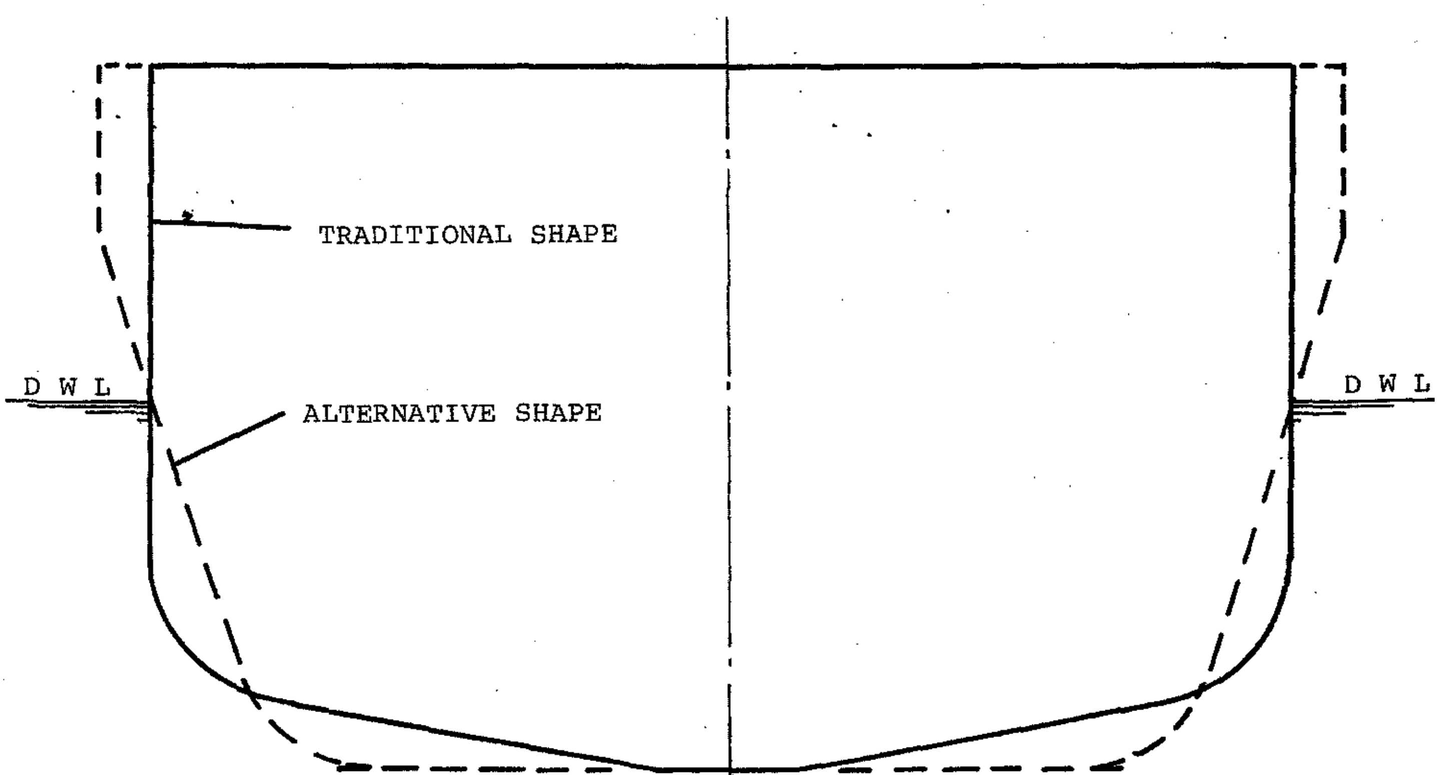

Figure 14.29 Flat Keel DFP Considerations

slight modifications which may have only negligible effects on the power requirements.

Flat keel The width of the flat keel plate used to be a rule requirement for most classification societies. Many developers of lines still use these standards as guidance. For designs with rise of floor, the selected width becomes the knuckle/chine in the bottom. This approach is not correct! The flat keel should be at least wide enough to extend over the keel blocks to allow for welding of one of the seams as an erection seam when the blocks have a longitudinal break along the center of the ship. Where the bottom block spans the blocks, this is obviously not a factor. It is suggested that two other aspects must be considered to decide the width of the flat keel. The first is that the shipyard maximum plate width should be used as the flat keel width. The second is that if one of the seams is used as an *erection joint*, the flat keel width must suit the block joining method, including the design detail of the internal structure. These concepts are shown in Figure 14.29.

Maximum section shape The design of the maximum section of the hull considers bilge radius, rise of floor, and slope of sides. There is considerable guidance available to the ship designer on the maximum section coefficient based on resistance aspects. Obviously, the required coefficient can

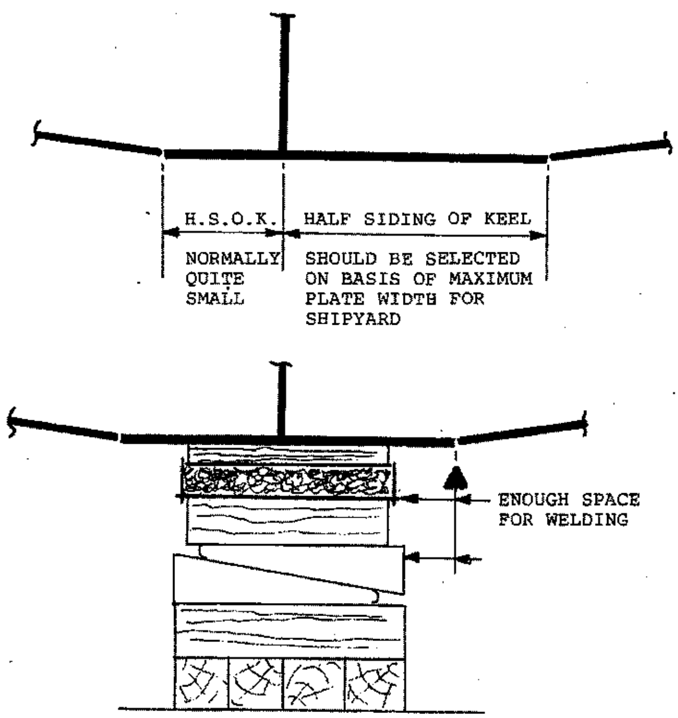

Figure 14.30 Alternative Maximum Section Shape for DFP Consideration

be satisfied by a combination of bilge radius, rise of floor, and even sloping sides (Figure 14.30).

The bilge radius should be selected so that the side block erection joint is above the tangent of the ship's side to the bilge radius, and above the tank top. In single bottom ships it may be preferable to select the bottom bilge radius seam as the erection joint and then the radius should suit this. The use of conic sections for the bilge shape as it moves forward and aft of the maximum section would result in the bilge shape being an ellipse and not a circle. The designer must appreciate this fact so that the intent to have circular sections can be correctly incorporated into the lines. If this is not done it may result in significant increase in work content as the shell plates must be formed to elliptical roll sets instead of a simple radius.

Single-screw skeg The afterbody lines of a single-screw ship are selected to provide low resistance and good flow to the propeller. Normal single-screw aftbodies are another part of the hull where reverse curvature is found. This reverse curvature can be eliminated by carefully locating plate seams and butts at the transfer lines from convex double curvature plates to concave plates. Even though double curvature plates have less work content than reverse curvature plates, the work content is still significant. One way to reduce the work content of the afterbody even further is to separate it into two parts, namely the main hull and a *skeg*. This can be done in two ways. The first way is to attempt to follow the normal single-screw hull form as closely as possible by incorporating a chine or *multichines*, joined in section by straight lines or simple sections, as shown in Figure 14.31.

The chines would lie in flow lines to prevent cross flow turbulence as much as possible. The second way, is to design the afterbody as a *cut-up stern* type, and add on a skeg as shown in Figure 14.32. Both approaches can usually be used without any adverse impact on propulsion power. However, the latter approach has the least work content.

Bulbous bows From a producibility point of view, the preferred shape of the bulb in the transverse plane is a circle. This shape can have some operating disadvantages, such as bottom slamming in a seaway. The next preferred shape that does not have the slamming problem is an inverted teardrop, but it has higher work content than the circular shape. A good compromise between design and production requirements is an inverted teardrop constructed from parts of two cylinders, two spheres (flat segments), a cone and two flats (Figure 14.33). A similar approach to developing producible details should be applied to other types of bulbous bows for large slow speed full hull form ships, such as tankers. Par-

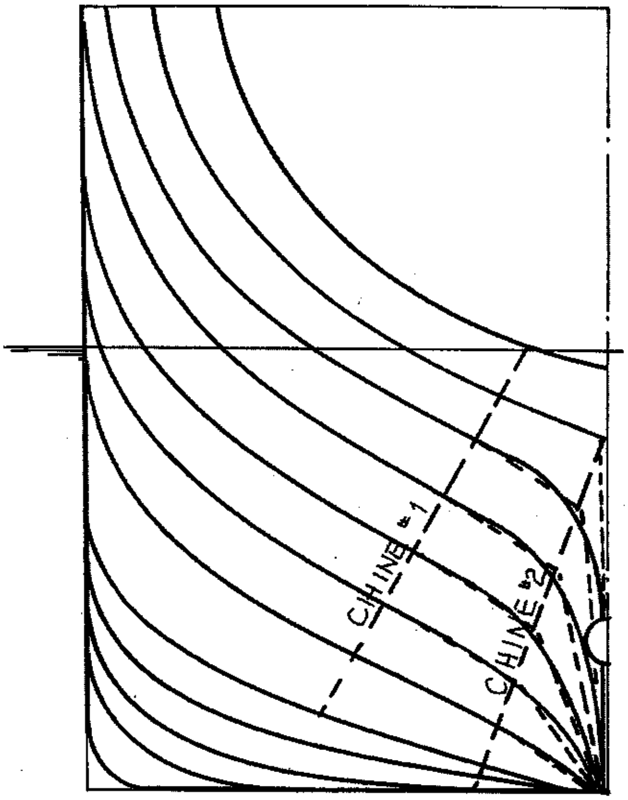

Figure 14.31 Use of Chines to Simplify Stern Construction

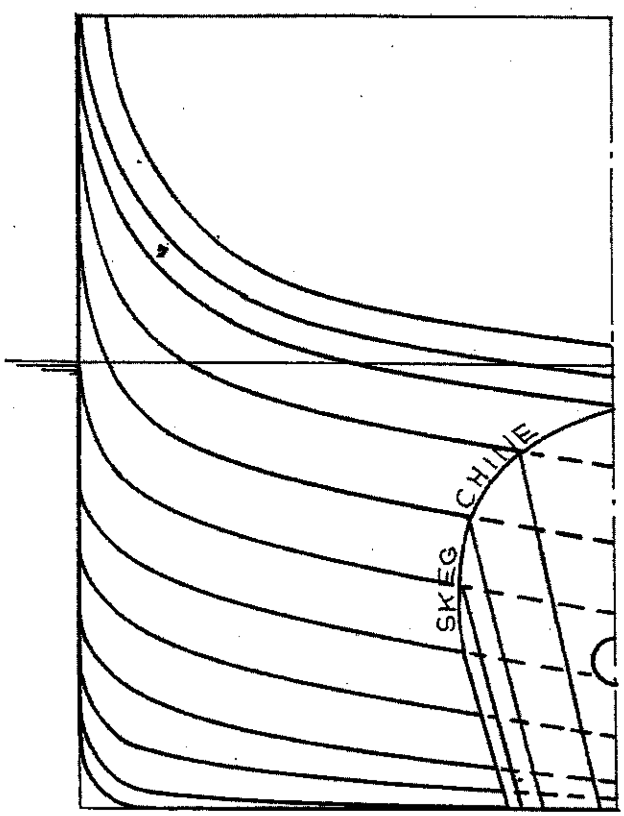

Figure 14.32 Use of Skeg to Simplify Stern Construction

tial stem castings have been used for bulbous bows where they are faired into the upper stem and shell. The casting can be eliminated by making the bulb to shell connection a chine (Figure 14.34).

Knuckles and chines Many ship designers utilize chine hull form designs on the assumption that they are easier to build than round bilge forms. Although this is generally true for small ships, it is not always appreciated that chines can add work content to a design. Before discussing this further, it is necessary to understand the difference between chines and knuckles. A formal definition of a chine is that it is the intersection of the bottom and side shell below the load waterline. However, it is usually used for any shell intersection curve, and in the case of double chine hull forms, reference is made to upper and lower chines. A chine is always on the shell and nowhere else. A chine is usually a curve in at least one plane. A knuckle can be anywhere on the ship. However, a knuckle is a straight line in two planes. Sometimes a chine located in the forebody above the load waterline is incorrectly identified as a knuckle because in profile it is a straight line. However, in plan view it is a curve.

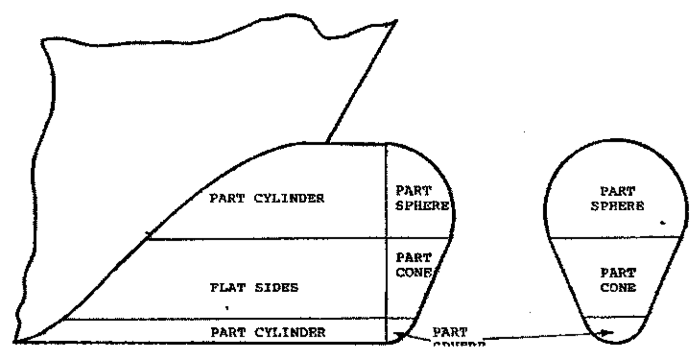

Figure 14.33 Bulbous Bow Using Regular Shape

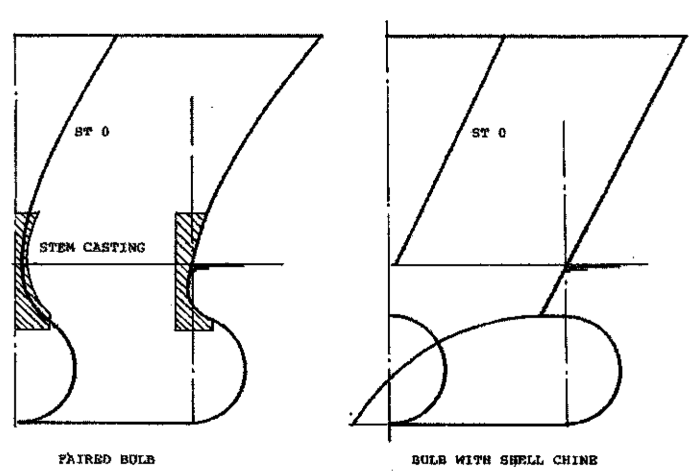

Figure 14.34 Faired versus Chine Bulbous Bow

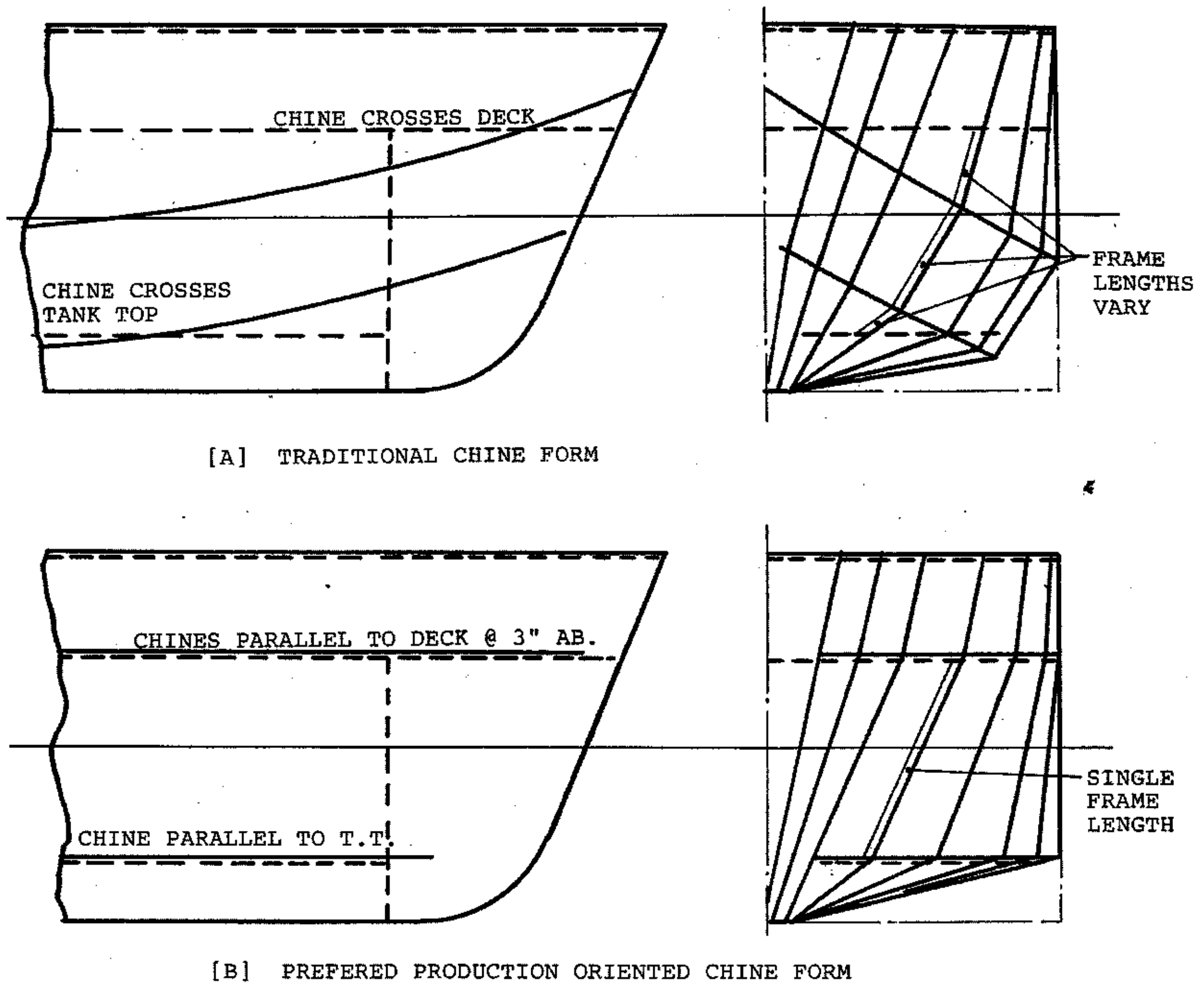

Figure 14.35 Hard Chine Producibility Considerations

When a chine is introduced into a design, and it is curved in the profile view, it can present a problem if the ship is constructed in blocks, as the chine is an obvious block erection joint. In addition, a chine that crosses a deck line introduces additional work content due to construction design details, including varying frame lengths and additional frame brackets. Chines are often located to follow flow lines in order to minimize any resistance increase. However, it is better, from a producibility point of view, to locate the chine parallel to the baseline/tank top/decks, as this enables the chines to be used as simple block joints and for simple alignment of the blocks. It also permits standardization of design details for floors, frames, brackets, etc. These concepts are shown in Figure 14.35, which also shows the problems with current chine shapes.

14.3.3.2 Arrangement design

When developing the arrangement of a ship, decisions must be made regarding the shaping of the hull, the location of cargo tanks, machinery spaces, holds, tanks and their contents, number of decks in the hull, number of flats in the machinery space, cargo handling gear type and capacity, accommodation layout, etc. It is, therefore, obvious that the development of the arrangement of a ship has a significant influence on its total construction work content. Yet it is usually performed with minimum production input. The construction work content is greatly affected by design decisions on the following aspects.

Bow The bow of a ship is one of the areas where designers regularly incorporate reverse curvature, apparently without any concern for its work content and thus cost. One only needs to look at a few ships to see this. Curved stems may be aesthetically pleasing but their cost must be appreciated. Even slight departures from a straight-line stem will add to the difficulty in fabricating it. The simplest above the water stem is one formed from cone (Figure 14.36).

This will give elliptical waterline endings, NOT circular, as most designers' use.

Figure 14.37 shows a DFP approach to provide flare in the fore end of a ship. Figure 14.38 shows the result from applying DFP principles to the bow of an offshore supply vessel.

Stern The term *stern* usually covers two important independent but obviously connected items, namely the propeller aperture and the rudder arrangement, and that portion which is mostly above the design waterline aft of the rudder stock centerline.

The single-screw propeller aperture has evolved from early counter stern combined rudderpost types to the *open* or

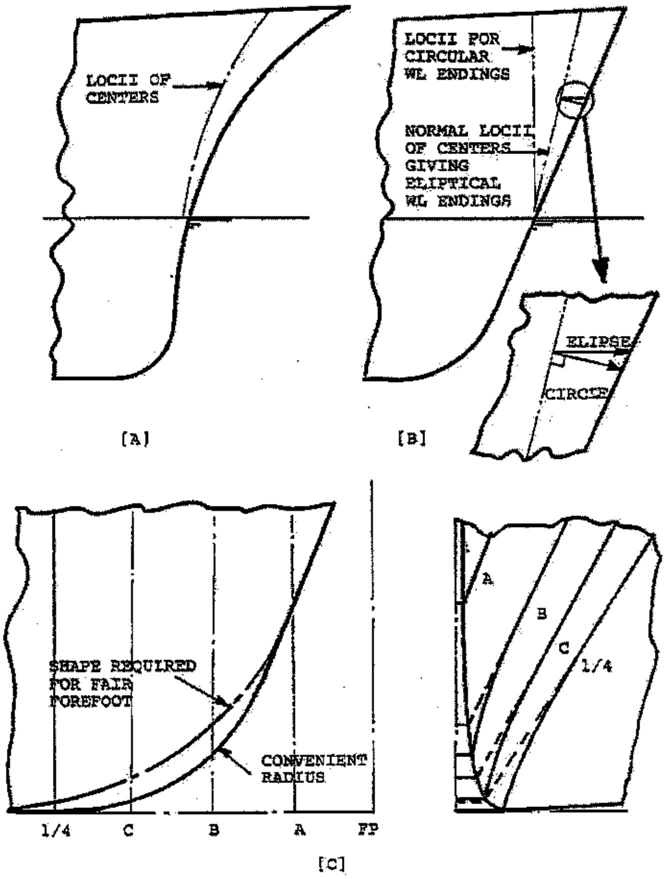

Figure 14.36 Stem Design for Production

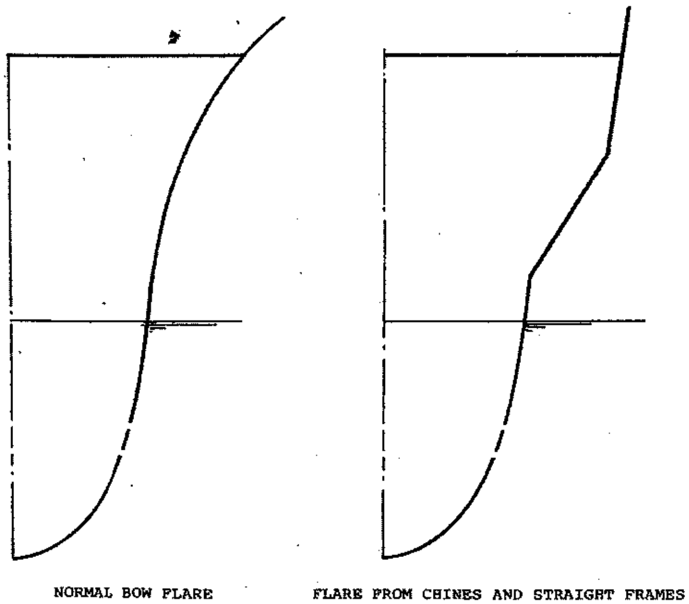

Figure 14.37 DFP for Bow Flare

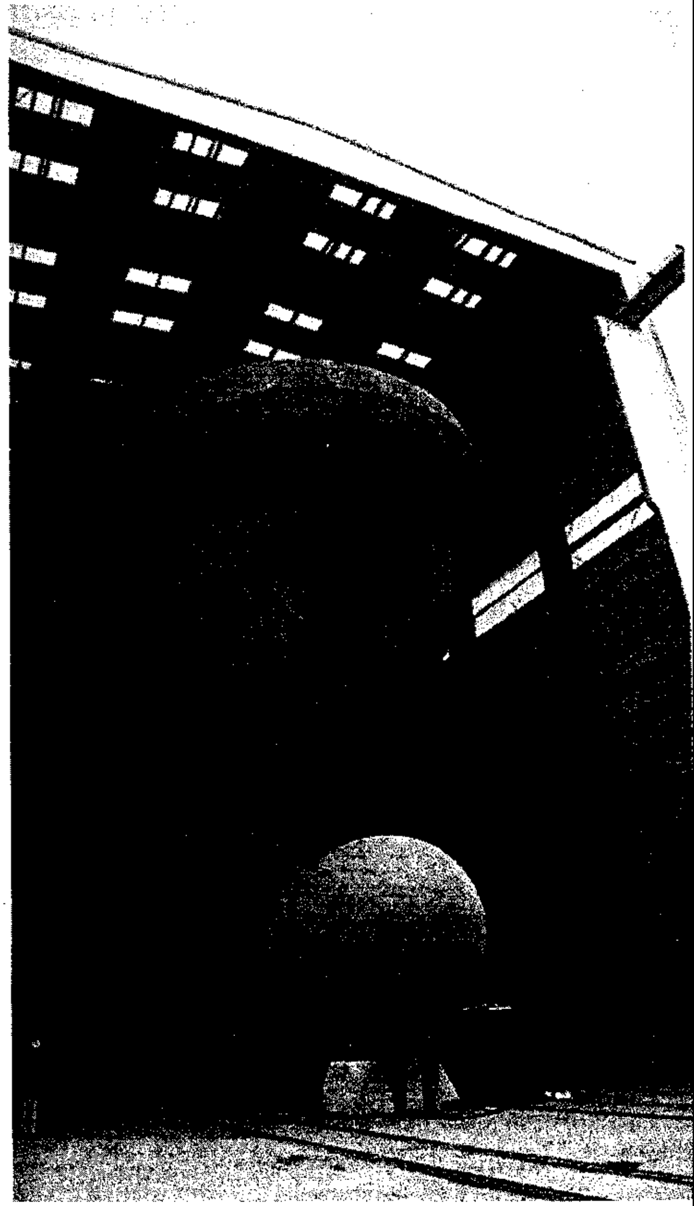

Figure 14.38 DFP Bow

Mariner style with spade or horn rudders. The design approach tended to favor *closed* apertures to reduce the size of the rudderstock to the minimum. However, even though it results in the largest rudderstock, spade rudders have the least work content if properly integrated in the design of the stern structure and if modern bearings are utilized. This can be seen by comparing all the parts and the various work sequences involved in both approaches as is done in Figure 14.39.

The upper stern development proceeded from the counter stern to the cruiser and then transom. Merchant ship designers adopted the transom stern because of its obvious economy, but also as it maintained deck width aft which was important in deck cargo ships, such as container ships and ships with aft deckhouses.

Unfortunately, designers still introduce aspects, which cause additional work content for transom sterns, by sloping it in profile and providing curvature in plan view as well as large radius corner connections between shell and transom. The design can be simplified by providing a vertical and flat transom, such as shown in Figures 14.40.

Hold or tank length The frame spacing should be constant throughout the ship's length with the exception of the peaks, where the usual practice of incorporating smaller spacing is required by classification society rules. In the case of bulk carriers and general cargo ships, some designers deliberately vary the lengths of the different holds and tweendecks to equalize the loading and unloading times (45).

It is suggested that the length of the holds or tanks should be constant throughout the ship so that they can be divided into standard structural blocks and then simply duplicated as required. For example, in a ship with five holds of which three are in the parallel body and each hold has four blocks, then only four different structural block drawings need be prepared for three holds. If on the other hand the hold lengths are all different, then twelve structural block drawings are required. When the standard hold concept is carried over into lofting, process planning and actual construction, the labor and time savings multiply quickly.

This approach is simply applying Group Technology on a macro level during Basic Design, thus ensuring it can be utilized at the micro level during Product Engineering, lofting processing and workstation manufacturing. If it is necessary to vary the length of some holds or tanks, the length should be one or two web frame spaces more or less than the standard length so that the standard drawings can be simply extended to the non-standard length.

Engine room location In small ships the engine room can be located anywhere in the length that provides a workable loading/trim relationship for the intended operations.

For large ships the engine room is usually located aft of amidships. A popular location for the engine room in cargo ships is the two-thirds aft position (46). In all cases the obvious producibility factors to consider are:

- length of shafting,
- engine room is not suitable for standardization of arrangement and structure. Therefore, the engine room should be located in the part of the ship least suitable for standardization, that is, the ends,

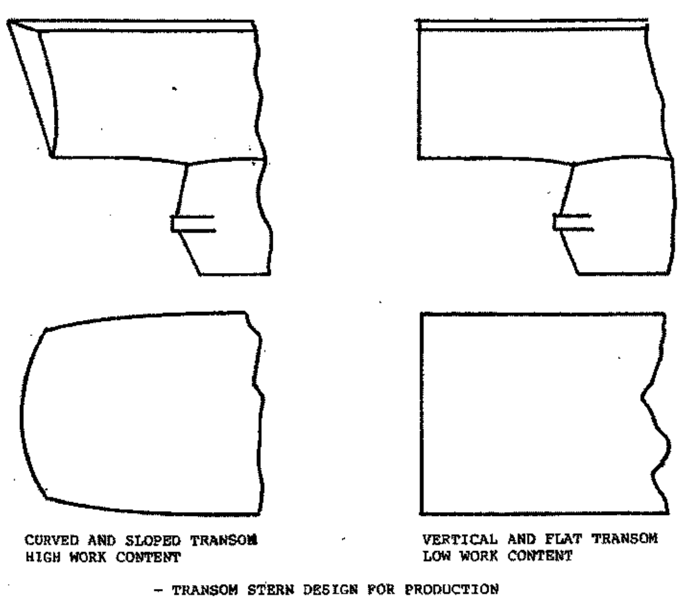

Figure 14.39 Rudder Type Selection for Producibility

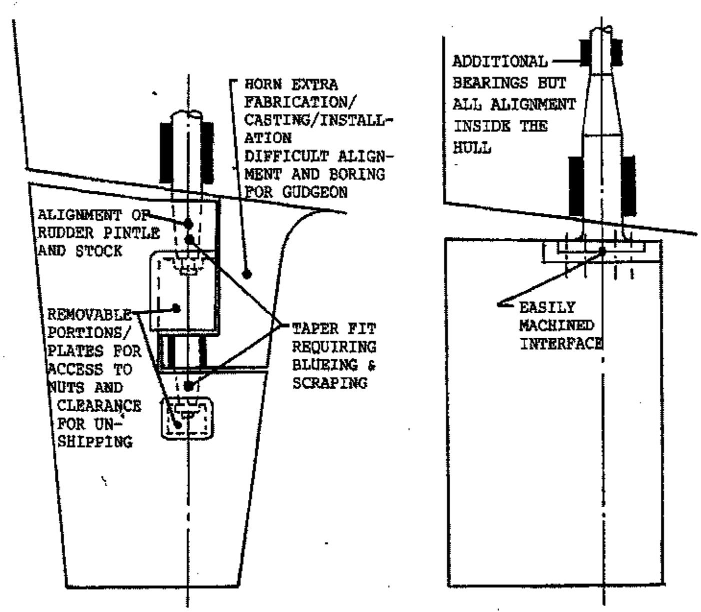

Figure 14.40 Stern Design for Production Considerations

- a shaft tunnel or alley is needed except for the all aft location, and
- an all aft deckhouse requires more tiers to provide adequate line of sight over the bow.

Before the recent skyrocketing increase in fuel cost, a number of novel machinery arrangements were developed,

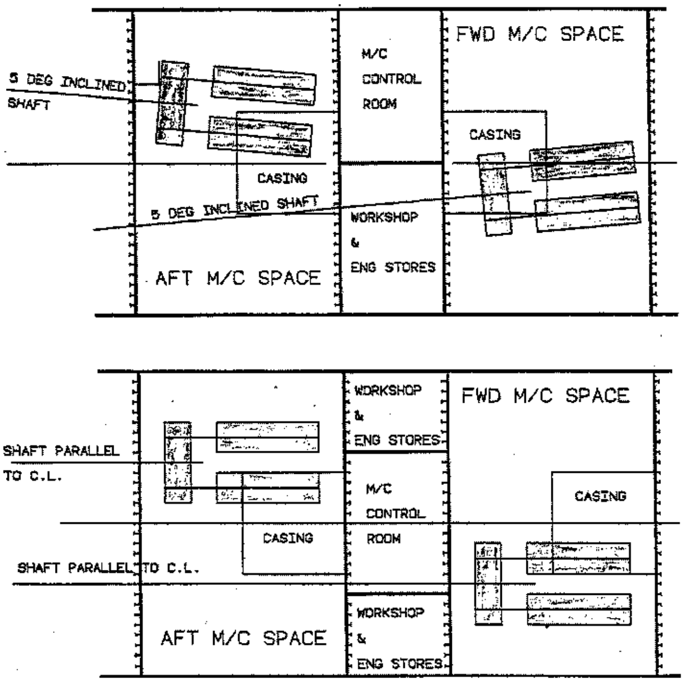

Figure 14.41 Machinery Room Arrangement Design

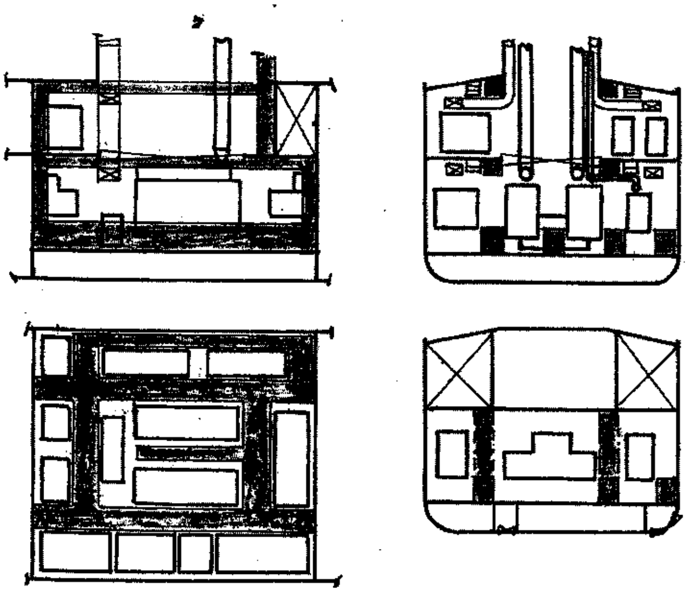

Figure 14.42 System Corridors

usually for novel ships, but sometimes for traditional ships such as tankers and bulk carriers. They were proposed for both reductions in material and operational costs as well as ease of construction. Some of these, which impacted productivity, were:

- split engine rooms above main deck with azmuthing propulsors,
- propulsion engines in twin skegs, and
- gas turbine/electric with GT generators above main deck.

Machinery space arrangements It is essential that producibility be adequately considered during the development of the machinery space arrangement, not only in the equipment layout, but also for the surrounding structure. This can best be illustrated by an example. Figure 14.41 shows a typical large naval ship machinery arrangement consisting of two main machinery rooms and a central control room. The ideal, from a producibility point of view, is that both machinery arrangements should be identical.

The next best is to make the arrangements mirror images about the centerline of the ship. Obviously, only the aft space has two shafts in it. The forward space should simply be a mirror image of the aft space with the transiting shaft deleted. This is only possible if the shafts are parallel to each other and are horizontal. Unfortunately, this is often not possible, and the different spread angles and shaft slopes prevent exact mirror image spaces. Even in this case, the machinery rooms can still be mirror images except for the propulsion machinery setting.

The mirror image requirements also apply to the surrounding structure as well as the machinery and equipment. It can be seen from Figure 14.41(a) that duplicity of arrangements in the machinery rooms and surrounding structure was not attempted.

The following differences can be noted:

- the forward and aft transverse bulkheads in each room are stiffened on different sides,
- the casing is aft in one room and forward in another, and
- the control room is oriented differently to each room.

It is obviously easier to insulate a flush bulkhead than one with stifferenrs. This is because each stiffener has to be wrapped and the bulkhead insulation has to be cut into strips and installed between the stiffeners.

Figure 14.41(b) shows the same spaces with the arrangements developed to minimum necessary design, lofting and installation work content by incorporating duplicity as much as possible. It should be noted that the control room is now in the same relative transverse location for each room, but obviously it is not longitudinally.

The layout of the auxiliary machinery has a major producibility impact, and, therefore, it is important to arrange it in the most effective way. Today that means equipment package units, piping/ grating units and advanced outfitting. This is because advanced outfitting is driven by labor and schedule reduction goals, such as straight lengths of pipe, right angle pipe bends and combined distributive system/grating support units, all of which are manufactured in ideal shop conditions. However, the basic requirement in the design of engine rooms is the ease of machinery plant operation and maintenance and must be met and not impaired, regardless of the method of design and construction. Fortunately, the procedures used for developing advanced outfitting design are compatible with this basic requirement. If it is attempted to lay out auxiliary machinery during Basic Design, it must be determined if advanced outfitting of the machinery spaces is intended as certain approaches must be followed if it is.

Even if advanced outfitting is not intended it is still a good design to approach the arrangement of the machinery space(s) into associated equipment groups and service corridors or zones (Figure 14.42).

It is suggested that only the unit boundary need be shown and the equipment within each boundary listed.

If the ship designer does not take such matters into consideration and prepare production oriented Contract Machinery Arrangements, it is strongly suggested that the document they prepare be designated as a Contract Guidance drawing, and only be used to show required equipment and any preferred layout.

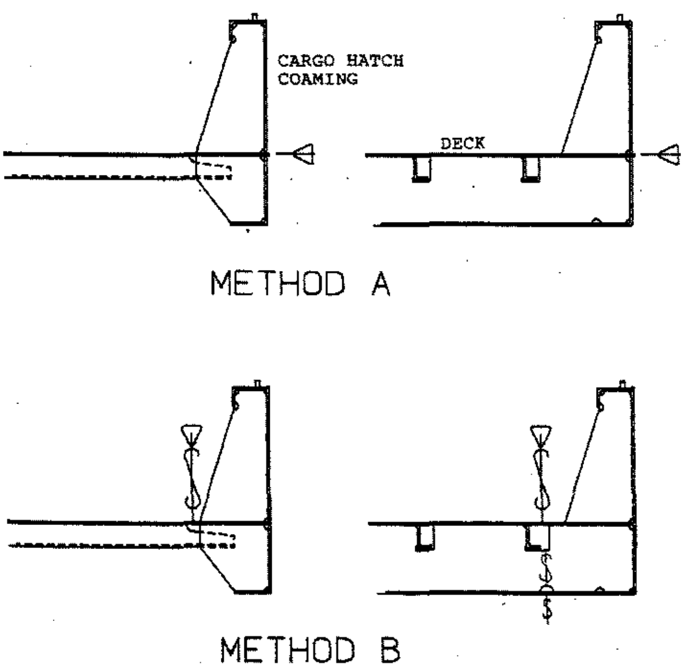

Figure 14.43 Hatch Installation Alternative

Cargo hatch sizes Standardization is the major producibility goal that should apply to cargo hatchways and hatch covers. All cargo hatches should be identical on a given ship or size of ship for a given shipyard. This would allow hatch coamings and covers to be designed and lofted only once, and to be built on a process flow basis. In addition to size and detail, the location of the hatches relative to the hold transverse bulkheads should be identical. The block erection sequence must also be decided at the earliest possible time, as it will obviously affect the design, and, in turn the work content for the hatch block and its installation. This can be seen from Figure 14.43, which details two possible design approaches that could be used.

Method A shows a hatch coaming that would be erected on top of the deck. It usually requires stock or green material to be left on the lower edge of the coaming for scribing to the deck. Also, the fillet welds of the coaming to the deck are not suitable for machine welding due to the brackets on the outboard side, and the absence of a work surface for the machine on the inside.

It will be necessary to provide staging inside the hatch coaming for workers welding the inside fillet.

Method B incorporates part of the deck in the hatch block. Any stock or green material would be on the inboard edges of the deck plating and the hatch block could be easily fitted using its deck plate edge as a guide to scribe the deck plate. It should be obvious that Method B allows machine welding of the deck seams and butts. No staging would be required although a personal lift may be required to fit the ceramic backing tape to the underside of the deck seams and butts.

Double bottom height The height of the double bottom is usually derived from the appropriate classification rule depth for the center vertical keel. Most double bottom spaces are small with difficult access for both workers and their tools. A problem often results from deciding the double bottom height based on the midship section shape. The bottom shape rises both forward and aft of the midship section, and this reduces the height in the double bottom outboard. Therefore, it is necessary to consider the double bottom height at the location where the hull shape reduces it to a minimum at the double bottom ends fore and aft and outboard.

It is possible to use a smaller double bottom height with transversely framed ships than with longitudinally framed ships. This is because for longitudinal framing, the transverse plate floors need to be deeper to allow for a reasonable distance between the longitudinal cutouts and access holes, as shown in Figure 14.44.

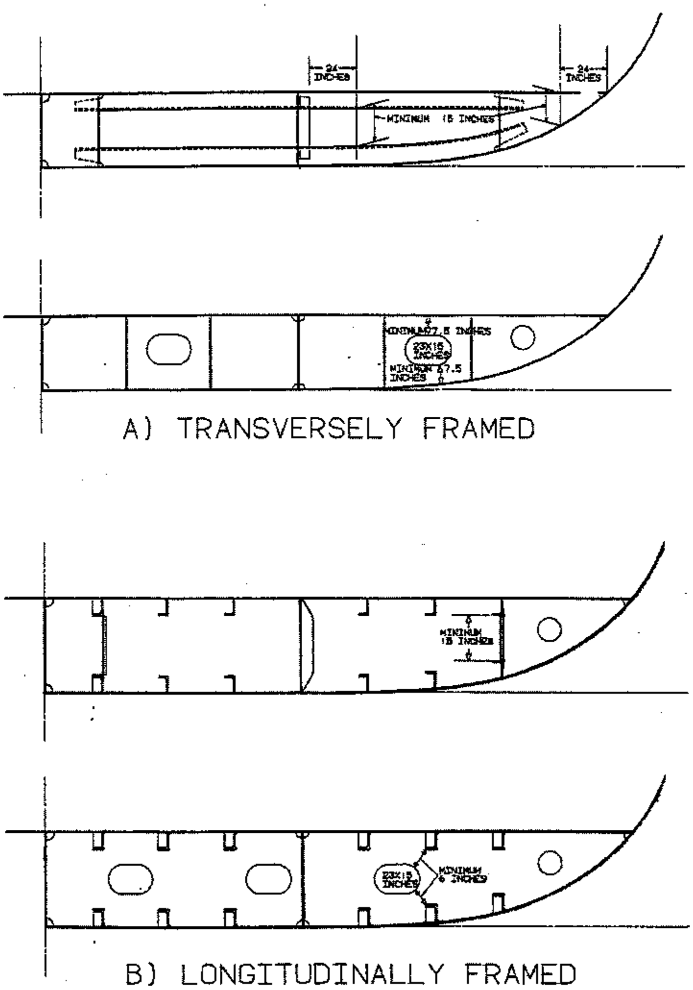

Figure 14.44 Factors Affecting Double Bottom Height

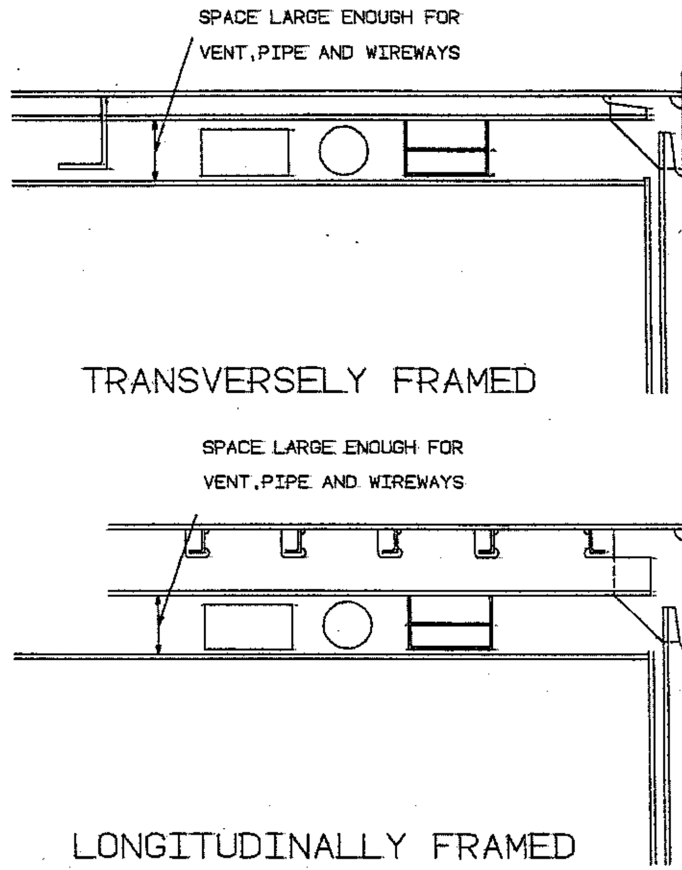

Figure 14.45 Required Space for Services

Tweendeck height The tweendeck heights may be decided by an operational requirement, such as use of standard pallets, hanging refrigerated meat, maximum number of boxes that can be stowed on top of each other, carriage of containers, RO-RO cargo, etc. In such cases the deck level must be selected to allow cost-effective design of ship structure.

In way of accommodation spaces, the tweendeck height should be selected to allow high productivity installation of the overhead vent ducting, piping and wiring. If it is difficult for the designer to squeeze such systems into the allowable space, it will be many times more difficult and use higher production man-hours for the worker to install the items. It is usually possible to use a smaller tweendeck height in accommodation spaces with transverse beams than longitudinals.

This is because longitudinally framed deep deck transverses add to the required height for fore-and-aft run services. Therefore, if the deck is longitudinally framed, additional tweendeck height should be provided. This requirement can be seen from Figure 14.45. Another possible approach, which is applicable to modern construction methods, is to select zones over service areas, passageways and toilets, and provide only the allowable minimum clear deck height in way of the zones (Figure 14.46). The specified clear deck height is maintained in all other areas.

Corregated and swedged bulkheads One very effective way to reduce work content as well as the weight of the structure of a design, is to use *corrugated* and *swedged* stiffening for bulkheads, deckhouse decks and sides (Figure 14.47). The work content is obviously reduced due to the reduction in the number of parts to be processed and assembled, and joint weld length, but it is also due to the elimination of weld deformation of thinner plate. There is an increase in work content due to the forming effort, but the net result is a significant work content reduction.

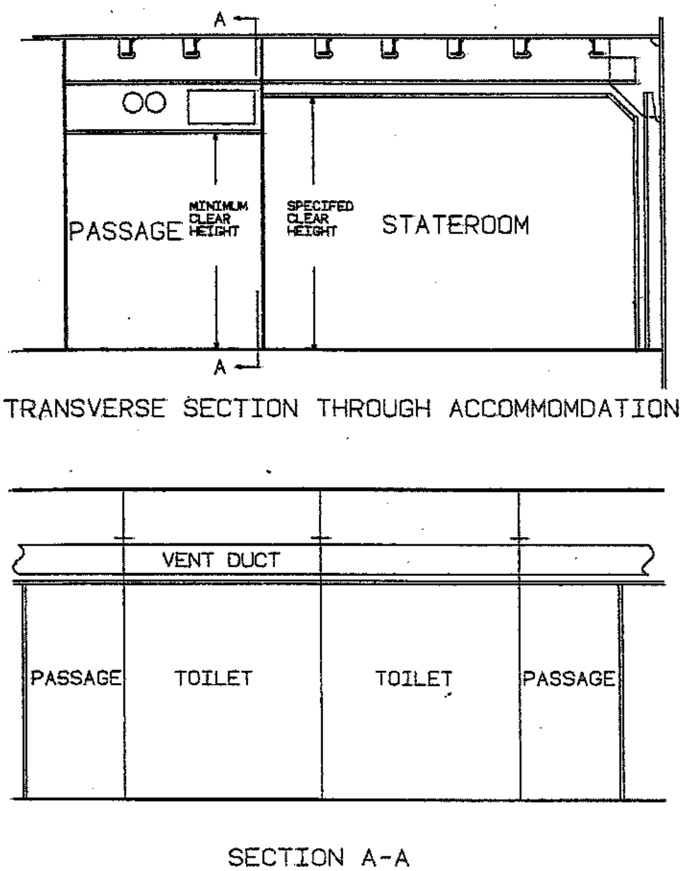

Figure 14.47 Alternative Stiffening Methods

Corrugated bulkheads can be effectively integrated with access ladders, pipe corridors, space ventilation and other items passing through the space. Corrugations for transverse bulkheads could be either vertical or horizontal, but for longitudinal bulkheads they must be horizontal. Finally corrugated bulkheads have the additional benefit of facilitating robotic tank washdown due to their elimination of stiffener shadow zones to the cleaning fluid.

Swedged bulkheads can be used for tweendeck structural bulkheads, and for all miscellaneous non-structural steel or aluminum bulkheads. Swedges must be vertical. Swedged stiffening could also be used for decks inside deckhouses. For short deckhouses with no influence on the ship's longitudinal hull girder strength, the swedges could run transversely. For long deckhouses, the swedges should run longitudinally. The decks would be swedged downwards and the trough formed by the swedge filled with deck covering underlayment.

One disadvantage of corrugated and swedged construction is that it prevents machine welding of the edges perpendicular to the corrugations or swedges to the connecting structure. This can be overcome for swedges by developing welding machines especially for this purpose, and in the case of swedges, by modifying the ends so that the intersecting edge is straight.

Location of block breaks and tank bulkheads From a production point of view, it would be ideal if the tanks in each erection block could be completed and tested before erection. This would enable any defects to be easily corrected on the block construction platens. This is not possible when common tank boundaries cross or are located at erection joints. Usually, only a portion of the tanks needs to be hydraulically tested, and then the erection joints should be located in the tanks that will not be hydraulically tested. In addition, if the tanks were to be coated, it would be preferable to have no block connecting welding which would damage the coating, thus requiring rework.

One way to achieve this ideal would be to provide cofferdams in way of erection joints. This would reduce the amount of usable space in the hull for tanks, and would increase the steel weight. The work content would also increase due to additional manholes, sounding tubes and air vents. However, it could still be a productivity net improvement depending on the design, extent of required testing and tank coatings. Figure 14.48 shows this concept.

Deckhouse shape and extent of weather decks Sloping house fronts, exterior decks along the sides and aft bulkhead, and sweeping side screens all add significant work content to the task of constructing a suitable deckhouse to accommodate the crew, and provide the necessary operating and service spaces.

While certain ships such as passenger and cruise ships can justify the additional cost of such aesthetic treatment, in general, they are unnecessary additional work content for all other types of ships. They not only increase the construction cost, but they also cost more to maintain during the ship's operational life.

The ship designer should develop simple deckhouse design utilizing vertical and flat deckhouse fronts, and provide exterior decks that are required only for the safe access and working of the ship. Figure 14.49 shows the two extremes, and the additional work content can be clearly seen.

Sheer and camber Eliminating sheer and camber results in a flat deck, which has less work content than a deck with both. This is due to eliminating the need to form the decks, the deck beams, angle the deck beams and form the deck

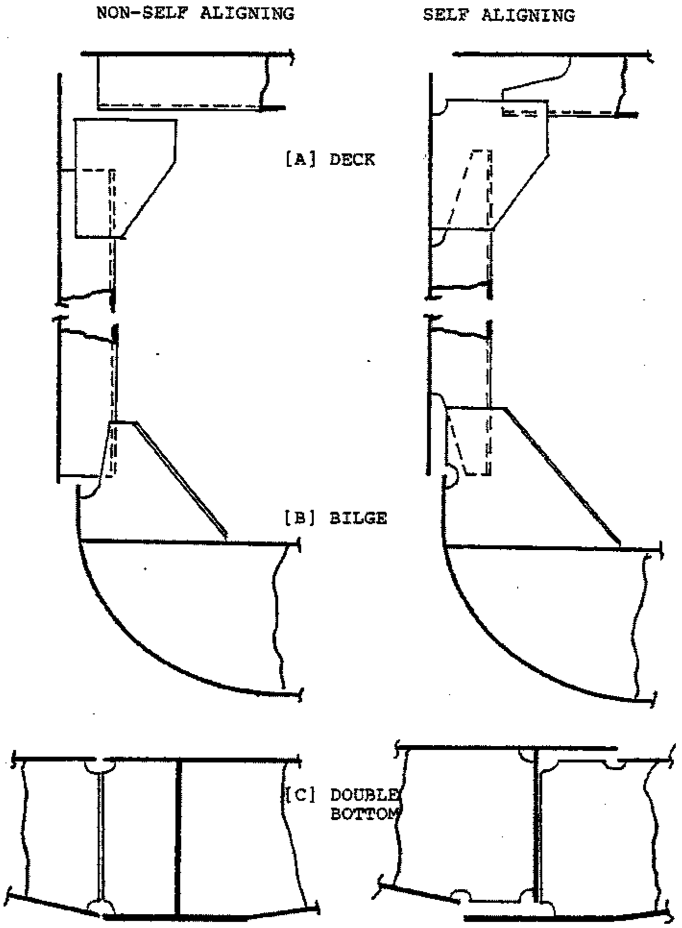

Figure 14.48 Block Breaks DFP Considerations

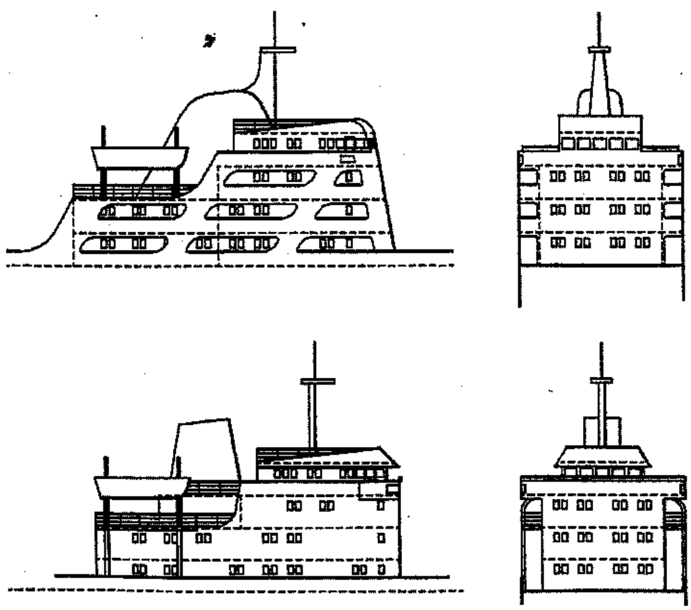

Figure 14.49 Aesthetic versus Cost Effective Deckhouse Design

girders. This applies to decks in the deckhouse and superstructure as well as the hull. For some designers and owners the elimination of sheer and/or camber is a very emotional matter and they argue that sheer and camber improve the seakeeping and other operational aspects of the ship. The other side logically argues that this is not the case because ships are seldom level when at sea, and even in port they usually have trim and heel.

Access for workers and equipment The arrangement designer must consider how the ship will actually be constructed, and provide adequate access and working levels, including permanently built-in solutions, for workers and their equipment during the construction and later maintenance of the ship. Some ideas in this regard are:

- service trunks, corridors or zone for deckhouses and above machinery spaces,
- cofferdam under deckhouses that will be constructed and outfitted completely before erection on the hull or between two blocks of a deckhouse erected in two tiers, and
- galleries in tankers, which eliminate need for staging (Figure 14.50).

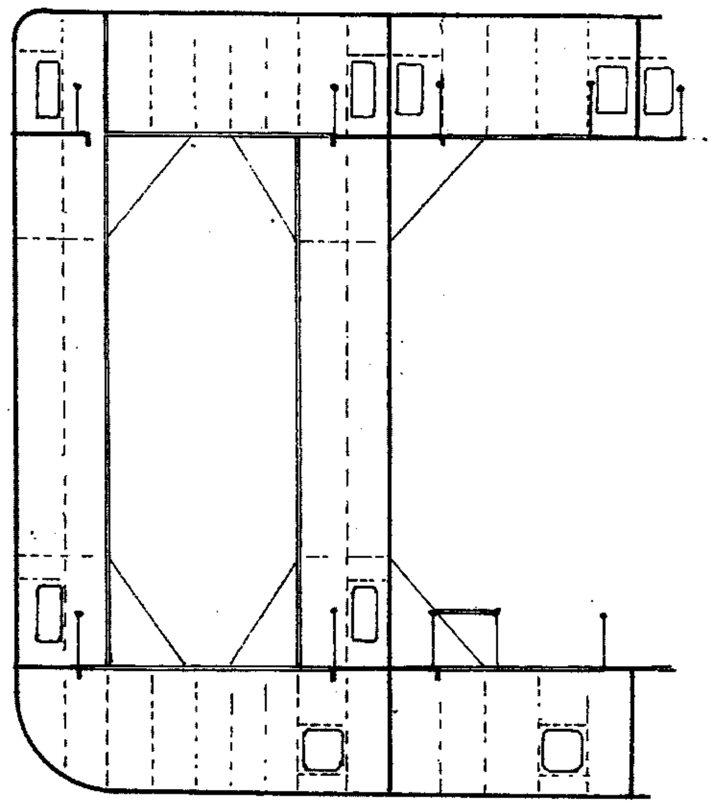

Figure 14.50 Built-in Access Galleries