Advantages of Software Integration from Initial Design through to Production Design

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Abstract

Advanced software packages are now commonplace for marine vehicle design and manufacture, however very few address the need to integrate the earliest design stages with the eventual production process. This capability is known as Design For Production (DFP).

GRC Ltd and SENER SA as developers of marine vehicle design and production software have joined forces to integrate their design and production packages. The resulting capabilities will allow modern DFP techniques to be accessible at the initial design stage and enable evaluation of DFP issues right from the outset.

A relevant aspect of this collaboration has been the integration of an advanced surface modeller with a 3D general arrangement system based on powerful solid modelling capabilities. Keeping the topological relationships has been an objective in this integration.

The building block philosophy recently developed by GRC in conjunction with University College London for "functional design" is linked with production processes to generate the feasibility and costing data associated with a particular build strategy. Therefore different shipyard facilities can be taken account of and the specific construction costs for a particular ship or submarine design ascertained. Such cost and capability information is deliberately not "hardwired" as it is proprietary and varies considerably according to the facilities (production processes) of a given shipyard.

The final objective is to reduce rework, remove redundant complexity, and reduce the risk of an impractical production design feature being discovered late when the design moves to full development and production.

Introduction

The purposes of this paper are, firstly, to show that Design For Production (DFP) is an important philosophy which cannot be ignored at any stage of design, and secondly, to show that an integrated Design For Production capability is now possible with present-day technology.

Taking the first point, why bother designing a ship in order to facilitate its production? There is a large number of issues to be considered during the design of a marine vehicle, beginning with the basics such as “will it float?”, “is it strong enough?” etc. To answer this, it is worth considering the following real-life situations:

1. An organisation tenders for shipbuilding contracts on the basis of concept designs for vessels carried out in-house which do not address DFP. Once the contract is awarded, the vessel must be completely re-designed, this time to ensure that the vessel can be produced. This design effort not only adds cost to the procedure, but introduces a significant level of risk that the design is no longer feasible as originally envisaged and therefore needs extra design iterations.

2. Typical problems that have occurred are where a unit butt joint cuts through systems at a point that “splits” a system apart where logically it should remain grouped together, for example pipe runs split half and half across a butt. Retrospective modularisation of systems after determining the construction zones is impractical. Instead the systems must be redesigned at considerable cost.

3. Systems make up 45% of the cost of a warship, so having to re-engineer them at the production stage is expensive.

4. Space envelopes for distributed systems have to be correct and include minor as well as major systems from the outset. They cannot “grow” later, at the production stage, to allow for the design phase omissions of minor systems because they immediately give rise to spatial clashes/overlaps. There is little capacity to accommodate additional systems piping runs, cabling, etc., much less removal routes.

5. Illustrative of the point above, a class of ship carries diesel generators which occasionally require removal for maintenance. The removal route for the diesel generators clashes with the ship’s galley. This means that whenever a diesel generator need to be removed, the entire galley must be stripped out. Although this is not a Design For Production issue *per se*, such a situation indicates either a failure to consider maintainability from the earliest stages of design, or else is symptomatic of the over-demand for space associated with point 4 above.

Having considered some of the problems, we next consider Design For Production as a discipline in its own right.

Design For Production

Design For Production as a philosophy seeks to match together the shipyard facilities (the *production processes*) with the ship type (the *product*). The principal aim of DFP as expounded by Andrews, Zhang and Batagva [1] at University College London (UCL) is to minimise production costs by:

(a) Minimised work content;

(b) Ease of assembly and construction, and the best use of available facilities.

For systems:

(c) To group multiple systems together (for example: piping, cabling and ducting grouped together along common routes).

(d) To combine systems into suitable outfit assemblies.

Following studies at UCL [1], a DFP method has been identified in which the vessel is divided into geometric Zones. Each Zone is then considered in terms of a time-based sequence or “production process” – each element of which is known as a “Stage”. Each combination of a Zone and Stage is then referred to as an “Interim Product”. Interim Products are groups defined by their particular production process and characterised by their size, material, and production operations required.

There are two major factors which determine the nature of Design For Production for a particular vessel: *design complexity* and *producibility*. The design complexity is concerned with how much manual and how much machine processing is required. Producibility is concerned with the need for such items as: jigs and support fixtures; work positions required and number of turns / moves; space access required; staging required; alignment and support; standardisation, etc.

As confirmation of the real-life situations presented in the Introduction, the UCL authors [1] declare that for vessels with high design complexity, it is essential to consider production aspects of systems and outfit, including their routings, from the earliest stages of design in order to reduce the work content associated with production aspects of the vessel’s systems.

Storch, Sukapanpotharam, Hills and Bruce [2] have discussed Design For Production from the point of view of CAD systems and the concept of Mass Customisation. They define the latter as “the mass production of individually customized goods and services. It obtains economics comparable to mass production but also provides the flexibility needed for individual customers.” They then describe the concept of Common Generic Blocks, modular designs of individual block assemblies for ship designs. A design process is described, in which Functional Design represents the classical ship design processes, and Transition Design interprets the Functional Design according to rules for production. Transition Design is undertaken with a database of Common Generic Blocks in order to produce a Mass Customised design.

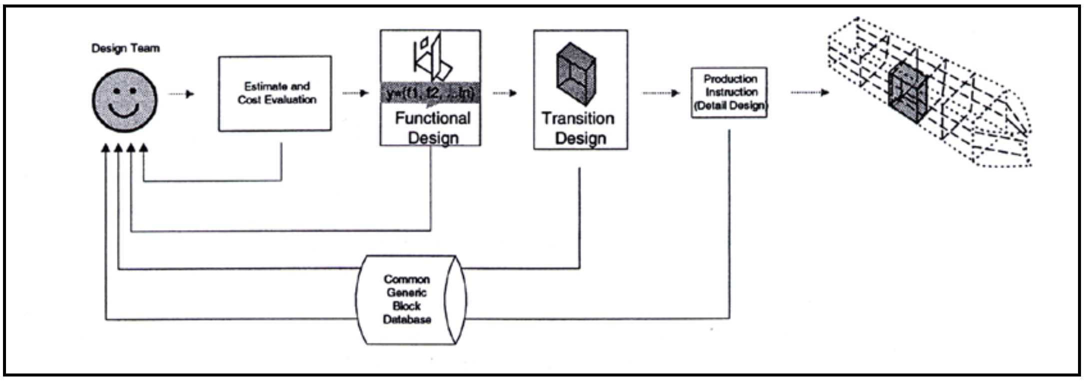

Figure 1: "Information Feedback from Transition Design and Production Instructions" taken from [2]

The authors also describe a methodology for quantifying the level of complexity associated with the production, the so-called Block Complexity Matrix.

Having reviewed some of the thinking about Design For Production, it is now appropriate to ask what software tools exist to help address Design For Production during early design. This paper describes tools from two organisations which are first described separately, and then as a unified whole based on the integration that has been undertaken.

GRC Software

GRC has developed a new software architecture based on Object Oriented technology and an industry-standard solid modeller. Products using this architecture include Paramarine (single seat) and Ultramarine (a multi-user, concurrent version).

The central philosophy underpinning these products is that users should only see up-to-date information. During a ship design, when characteristics are constantly changing, it is difficult for a designer to keep abreast of all aspects of the emerging design. With the configuration control of design data provided by Paramarine, the burden of keeping up to date shifts from the designer to the software, thereby introducing some intelligence into the design definition. Further discussion of this aspect is provided in Forrest, Dohrn and Voß [3].

Early Stage Design

The Early Stage Design capability of Paramarine has been developed in consultation with University College London (UCL) and provides an implementation of UCL's "SURFCON" philosophy (Andrews et al [4]; a submarine equivalent – "SUBCON" – is described in Andrews et al [5]). This is a novel means of vessel design, in which the design is broken down in terms of functions. In the archetypal initial breakdown, below "the design" are the functional areas "float", "move", "fight" and "infrastructure". For vessels other than warships, one might substitute functional headings of "mission" or "payload" for "fight". Other desired top-level functions such as "adaptability", or "maintainability" can also be used.

The "SURFCON" approach consists of refining the top-level functional headings into ever greater detail, maintaining a function-based approach. Thus under "float" one would expect to find the main hull, and its structure; while under "move" there would be the propulsion plant, propulsors, rudders, stabilisers, fuel tanks, etc. In Paramarine these functional areas are associated with "building block" objects, which can themselves have geometry and characteristics such as weight, space demand, power demand, etc. Alternatively these "building blocks" can act as placeholders for further "building blocks" and/or system and equipment definitions positioned within the design. In this way the design evolves functionally, and hierarchically, into ever greater detail. It is emphasized that the "building block" is a functional entity, not to be confused with a production unit or production zone.

Alongside refining of the functional definition, the designer can develop the 3D vessel layout and allocate the functional definitions to physical spaces in the ship.

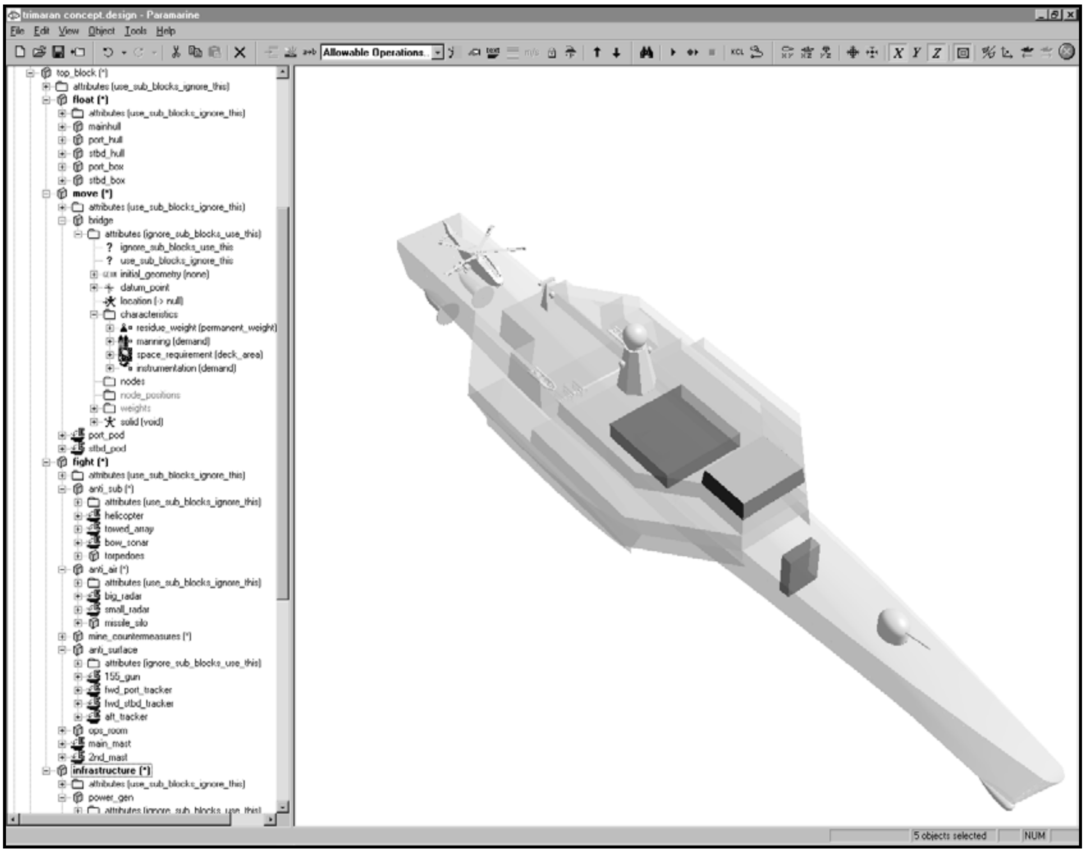

Figure 2: A screenshot showing "Building Blocks" and Equipments in a concept design

Once the design progresses to the point where systems may be defined, these are considered firstly in logical terms, that is, which equipments within the system are joined together and the nature of the connection between them (e.g. pipe, wiring, trunking, etc. - known generically as "Service Line Specifications"). When the equipments have been located in the vessel, the 3D trajectory of each connection (or "Service Line") is derived by the software. The user may specify one or more "Service Highways" through the vessel to define routes of distributed systems.

Auditing of the design’s characteristics is provided for, as well as performance evaluation in such areas as hydrostatics and stability, and automatic detection of imbalance in the design where demand for a characteristic exceeds supply. In addition logical checks are made to ensure that all necessary interconnection points between systems have been satisfied.

Structure

Once the designer has developed a 3D layout of the vessel, Paramarine provides a way of rapidly generating the panels of structure separating each space from its neighbours. It is then possible to define the structural scantlings and other attributes of each panel. Such a structural definition can be subjected to appropriate forms of analysis, such as Classification Society assessment or first-principles structural analysis, or even (in the case of warships) vulnerability analysis.

Design For Production

Paramarine allows the designer to carry out an early assessment of Design For Production issues at the initial design stages. Such assessment is intended to reveal any weaknesses in the build strategy proposed for the design. Once the designer has defined the 3D layout of production units (which may include a number of hierarchical layers of super-units composed of sub-units), the software will automatically determine what “building blocks”, systems, equipments, and structure will be present in each production unit.

In the case of systems, the software will determine whether the line-up of production units is such that systems are split between production units. Such situations will demand some form of connection interface to carry the system connections (Service Lines) from one unit to the next.

In the case of structure, the panels present in the structural definition are decomposed into underlying entities (plates and stiffeners) using simple producibility rules, and the “junctions” necessary to connect them together are then automatically determined.

Continuous junctions	**Discrete junctions**
plate/plate end	stiffener/stiffener end
plate/plate fillet	plate/stiffener end fillet
plate/stiffener toe fillet	stiffener/stiffener end fillet
built-up stiffener fillet	plate/stiffener intercostal
service line continuous	stiffener/stiffener intercostal
	service line/service line end

Table 1: Types of junction (for example, weld join) recognised by Paramarine DFP.

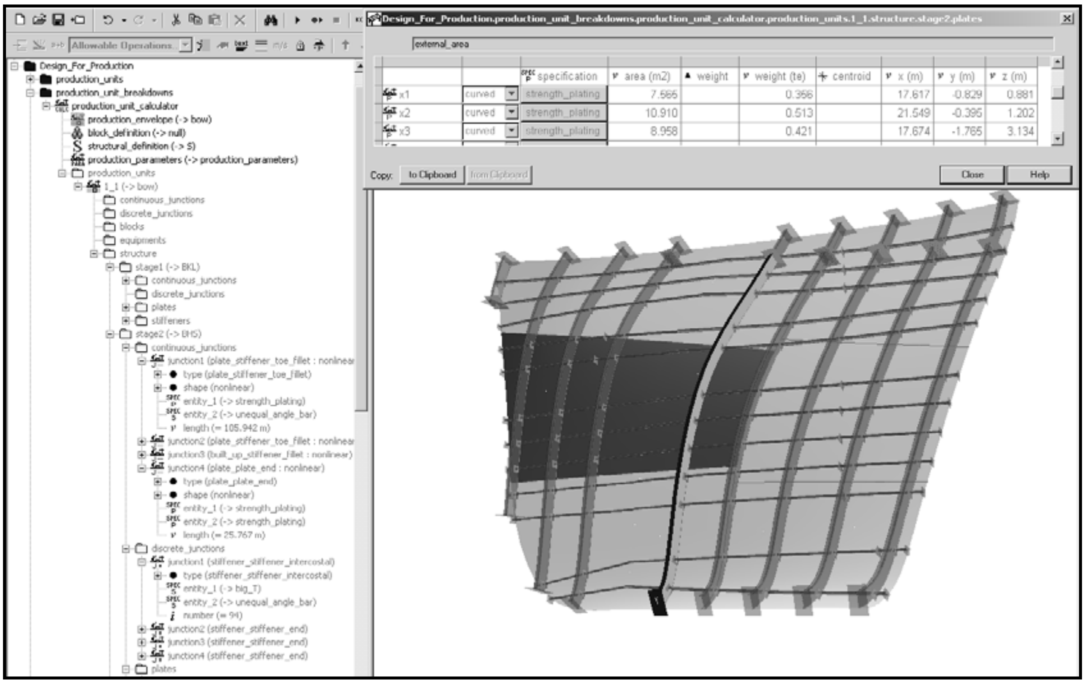

Figure 3: A screenshot showing the breakdown of the early design structure into production entities (plates, stiffeners, junctions)

Once the breakdowns have been computed by the system, it is possible for the designer to define costing information associated with each type of Service Line, plate, stiffener and junction. This information can be nothing more than confirmation that the shipyard *can* fabricate the Service Line, plate, stiffener or junction being considered, or alternatively can be a definition of usage of direct costs and/or resources which can themselves be associated with indirect costs.

Armed with such information it is then possible to derive preliminary production information about the design, via automated audits of the various aspects given in Table 2.

Aspect	**Nature of audit**
Areas	Summate internal and external areas by Service Line, plates and stiffeners. Designed to facilitate estimation of costs for coating (preservation, paint, insulation, etc.).
Costs	Summate direct costs and indirect costs (due to resources). Costs are itemised by type, e.g. labour, materials, consumables.
Dimensions	Summate bounding box dimensions - based upon the structure, Building Blocks, Systems and Equipments from the Early Stage Design. Assists in determining the construction location for stages, unit blocks, etc based on size requirements.
Junctions – continuous	Summate the various instances of one or more of the types of continuous junction. Results are given in length units for all scenarios found (for example plate/plate end auditing provides one column per pair of plate specifications being joined anywhere in the design). A further breakdown into linear or non-linear junction is provided.

Aspect	Nature of audit
Junctions – discrete	Summate the various instances of discrete junction for one or more of the discrete junction types. Results are given for all scenarios found (for example stiffener/stiffener intercostal auditing provides one column per pair of stiffener specifications being intercostally joined anywhere in the design).
Resources	Summate resource requirements in units of time. Resources are itemised by type, for example the different grades of construction worker and/or machinery, etc.
Specifications	Summate all Service Line, plate and stiffener specifications for the design. Results are given in terms of quantities required for flat and curved plate (area units), and for Service Lines and stiffeners (length units).
Weight	Summate weights - based upon the structure, together with Building Blocks, Systems and Equipments from the Early Stage Design. Allows decisions to be made about craneage, transportation, etc.

Table 2: Types of audit recognised by Paramarine DFP.

By investigating the variation in these audited quantities with changes in the line-up of production units, 3D layout, or the vessel's structural definition, it is possible even at an early stage to home in on an appropriate build strategy for the design, and thereby to avoid "building in" production problems from the beginning.

SENER Software FORAN

Single 3D Product Model

The FORAN product model contains not only the 3D model of each ship component, but also associative and parametric relationships, material definition, attributes and manufacturing data. The model is created once and increases in fidelity as the design matures from concept through detail.

Customisation

Libraries of standards, specifications and norms for the generation of the 3D model, are defined according to the practise of the shipyard. These libraries are then available for re-use in further projects.

Initial and Basic Design

FORAN incorporates a set of functions to facilitate the preliminary definition of the ship 3D model so that from the earliest stages of the project certain budgetary estimates can be carried out. Specific tools are also available to perform the basic design that allows the production of all the classification information.

Build Strategy

Structure and outfitting parts included in the 3D model are assigned to assembly interim units, so it is possible to generate all the fabrication and mounting information in accordance with the actual building process of the ship.

System Overview

Forms Generation

FORAN has an impressive capability for defining any hull form, including asymmetric ships and multi-hull vessels. The most advanced techniques are applied to create hull forms either from scratch or from any preliminary definition.

Further aspects of FORAN's hullform generation, and surface fairing/fitting capabilities are considered further under Integration Element 1, below.

Naval Architecture

FORAN features complete calculation of hydrostatic values, Bonjean curves, deadweight scale, cross curves of stability, freeboard, floodable and permissible lengths, sectional areas, trim diagram and cross curves of stability.

The System accurately evaluates the lightship weight distribution and inclining test, loading conditions and longitudinal strength. It also calculates flooding conditions and damage stability, by conventional methods and by probabilistic regulations.

Hull Structure

FORAN permits a fast definition of the hull structure, including shell and deck plating and profile parts and internal structure. The underlying topology allows the easy and fast reuse of the information of a component found in multiple locations.

Once the product model is defined, all the necessary information for hull fabrication, pre-assembling, mounting, material management, planning and quality control can be immediately and easily obtained, including the automatic nesting of plates and profile parts.

Calculation of weight and centres of gravity, painting areas and complete welding information of any set of parts or assembly units can be obtained easily and quickly.

Machinery and Outfitting

With the use of the machinery and outfitting modules, it is possible to create Piping and Instrumentation (P&I) diagrams, to position all equipment directly in the 3D model, to route pipes and HVAC ducts, and to create any kind of general outfitting structure such as foundations, ladders, supports or gratings. All the elements created in the 3D model can be referred to the frame system, hull surfaces, structural elements or any other item that has already been defined.

The result is a topological relationship between the elements, which is maintained even at the drawing level. On-line collision checking assures an interference-free design.

User configurable multiple production and mounting drawings and reports can be obtained from the 3D model, including the automatic generation of detailed piping isometric and spool drawings, tailored to the shipyard practice and formats.

Electrical

FORAN electrical application enables the user to incorporate into the 3D product model electrical equipment, cables and trays, as well as to define electrical one-wire diagrams. Cable routing may be automatic, semiautomatic or manual, with the possibility to determine the size of cables considering physical and electrical characteristics and service requirements.

Routing documents, such as lists of cables, wireway pull lists and drawings can be automatically obtained. Management of material lists and cable drums is also available.

Accommodation

The 3D product model is completed with all accommodation components such as cabins, sills, walls, ceilings, floors, doors, windows, panels, furniture, fittings, and insulation. The design can be made in a 2D environment or directly in the 3D model as preferred by the user. A modification in either of the environments automatically updates the other, so both working modes can be used to achieve the same final results.

Integration

From the foregoing sections it should be clear that the software systems provided by GRC and by SENER are complementary for complex vessels, such as warships. Paramarine is an impressive initial / early design system for complex vessels such as warships, while FORAN is well suited to the development of such an initial design into what are termed the basic design, detailed design and production arenas. By enabling these software systems to communicate with each other, the Design For Production process is streamlined considerably. We will therefore consider the steps that have been taken to integrate these systems together.

Integration has been implemented in three stages or "Elements" as shown in the following diagram. Each element is achieved by direct reading of the respective systems' databases, rather than use of neutral files, etc.

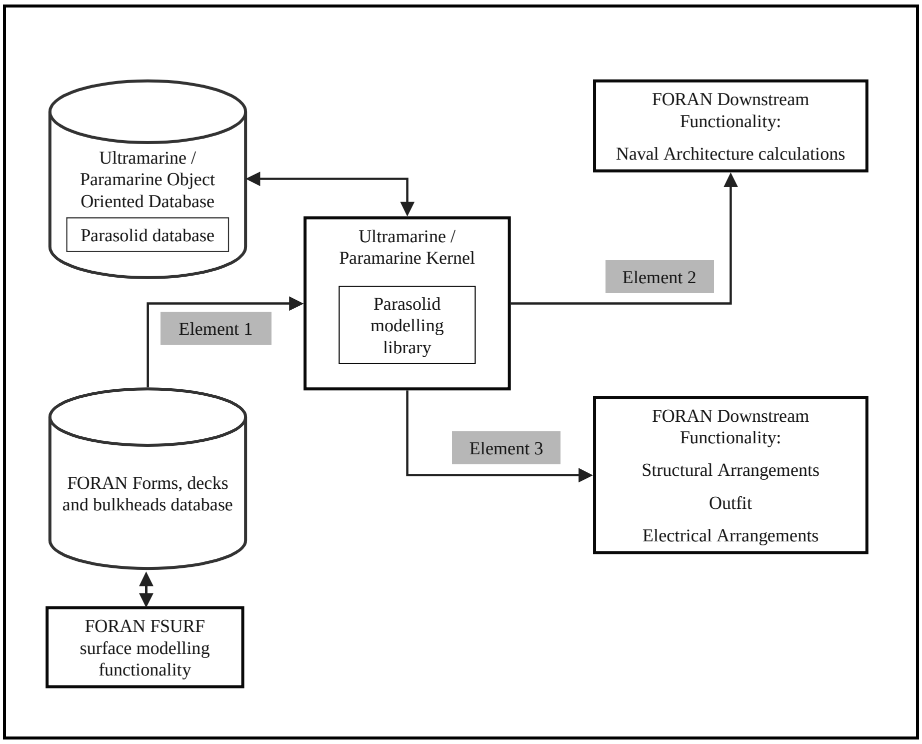

Figure 4: Elements of Paramarine/FORAN integration

The integration is transparent to the user, and the data is in general stored only once and accessed as required. This has been achieved by the development of special-purpose Application Programming Interfaces (APIs) in the respective software systems in order to satisfy the requirements of the integration.

Element 1: transfer of hullform data from FORAN to Paramarine

The starting point for any ship design definition is the geometry of the hull. FORAN possesses superior capabilities over Paramarine in this area by providing a "production-quality" hull from the first stages. Accordingly the first element of the integration is to enable such data, along with definitions of decks and bulkheads, to be imported into Paramarine.

FORAN has tools to transfer topological information about the geometric entities that compounds any relevant surface in the ship. As soon as a preliminary surface model is obtained, the following processes can start to work with this information. In parallel, the surface model is refined and faired, without preventing other tasks from going on. Once the surface model is finished, the work performed on the preliminary model is automatically updated, based on a topological definition. Topological definition is invariant for small changes (such as those changes introduced by the fairing process). Furthermore, FORAN has a wide range of tools to define the correct definition from the very beginning stages, so the production model takes advantage of these faired surfaces.

Among the tools available in FORAN for this purpose it can be remarked:

- Possibility of definition of model of curves, with special features:

- Interpolate a set of selected points or a polygonal. The user may have to introduce initial and final tangent conditions.

- Approximate a set of points or a polygonal.
- Predefined types of curves (mainly conic sections):

Once a preliminary curves model has been created, some additional work may be required to prepare the curves model to facilitate surface patches definition based on these curves. Part of this work is to fair the curves by different methods and the other is to merge, split and transform these curves to adapt their definitions to the way in which the patches are going to be created. This work can be done with the tools to edit, transform, fit, fair, join, merge and even redefinition of the curves. It is possible to use NURBS curve or polygonal lines. Each of one have their own methods. The quality of the model could be examined with different approach, including curvature, inflection analysis and even different projection analysis.

With a set of suitable curves the user can build surface patches. The quality of the patches produced will be directly related to the quality of these curves. Here, again appear a wide variety of possibilities to make this task in the better way to obtain a good design for production:

- Generate a new patch by skinning a set of curves considered as “generic” sections (they need not be planar sections) which is a very useful tool specially when the user is working with a large amount of information.
- Generate a new patch by blending four, three or two curves considered as boundaries.
- A combination of both methods mentioned above. In this case, the user will supply the system with information about boundaries and inner sections. Additional information that may be useful when creating the patches are the tangent conditions on the borders. Anyway, this information can be managed later in surface modification features.
- Surface edition.
- Surface transformation.
- Surface trimming.
- Surface boundaries sewing.
- Surface tangency edition.

Finally this FORAN module gives additional algorithms to analyse the smooth and the right definition of a hull. We can remark, among others: gaussian analysis, hole and overlapping detection, surfaces orientation, etc.

A complete structure manager allow to maintain the topological relation between the geometric entities and the main objects.

These “surface” entities are converted into Parasolid sheet bodies, to form a solid body definition of the hull, taking into account the main objects they allow to.

Any geometrical anomalies which occur during this process are highlighted in a convenient way for the user. Such anomalies may be resolved in FORAN prior to re-import into Paramarine – in this way the geometrical definition remains consistent between FORAN and Paramarine.

References to the geometrical entities imported from FORAN are preserved so that when downstream information is required (see Element 3), the original geometry can be readily identified.

Element 2: transfer of geometric property data from Paramarine to FORAN General Design (Analysis programs)

Once the designer has a solid hull, it is then possible to subdivide it using the modelling functionality provided by Paramarine.

When this process is complete, it is then immediately possible to use the hullform and its subdivision for analysis in Paramarine. Element 2 of the integration enables the subdivided hullform also to be the subject of FORAN Naval Architectural calculations. This means that users more familiar with FORAN than Paramarine can perform analysis and obtain results with the traditional look-and-feel of FORAN, but actually using a solid body representation of the subdivision obtained via Paramarine.

Element 3: transfer of data from Paramarine to FORAN (outfit and production definition programs)

The final step is to allow the 3D general arrangement of the ship to be read by FORAN. Element 3 allows for the transfer of geometrical information about the hull and its subdivided spaces from Paramarine to FORAN. This allows the downstream FORAN user to develop both 2D and 3D drawings, to visualise the hull layout alongside the outfit definition, and to perform such activities as clash detection. It may also provide a starting point for drawing up the list of zones for the vessel.

The information available for reading by FORAN from Paramarine database are either geometrical entities forming a body or a boundary representation of the same element. With this information it is possible to use the machinery and outfitting modules:

- To create Piping & Instrumentation (P&I) diagrams, to position all equipment directly in the 3D model.
- To route pipes and HVAC ducts.
- To create any kind of general outfitting structure such as foundations, ladders, supports or gratings.

All the elements created in the 3D model can be referred to the frame system, hull surfaces, structural elements or any other item that has already been defined or read from the Paramarine database.

The result is a topological relationship between the elements, which is maintained even at the drawing level. On-line collision checking assures an interference-free design.

User configurable multiple production and mounting drawings and reports can be obtained from the 3D model and or the 3D general arrangement, including the automatic generation of detailed piping isometric and spool drawings, tailored to the shipyard practice and formats.

FORAN electrical application enables the user to incorporate into the 3D product model electrical equipment, cables and trays, as well as to define electrical one-wire diagrams. Cable routing may be automatic, semiautomatic or manual, with the possibility to determine the size of cables considering physical and electrical characteristics and service requirements.

Routing documents, such as lists of cables, wireway pull lists and drawings can be automatically obtained. Management of material lists and cable drums is also available.

The 3D product model is completed with all accommodation components such as cabins, sills, walls, ceilings, floors, doors, windows, panels, furniture, fittings, and insulation. The design can be made in a 2D environment or directly in the 3D model as preferred by the user. A modification in either of the environments automatically updates the other, so both working modes can be used to achieve the same final results.

Summary

This paper has attempted to show that, for complex marine vehicles including warships, it is essential to consider Design For Production from the earliest stages.

It is furthermore shown that software is now available to assist in this effort. GRC's Paramarine provides state-of-the-art initial design capabilities for warships, including the capability to consider build strategy alongside other early design issues. SENER's FORAN is ideally suited to the downstream production definition of the design. Of greatest importance, there is now a substantial interface between these systems, enabling designs to be rapidly migrated from initial design to production design.

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