EFFICIENT DESIGN OF OUTFITTING & MACHINERY SPACES

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SUMMARY

This paper is devoted to analyse current FORAN system outfitting & machinery spaces design tools, reviewing how main drivers match features, and what is the solution provided for each case. At the same time, it describes the aspects in which FORAN can be further improved and the way to achieve it.

NOMENCLATURE

CAD: Computer aided design
CAM: Computer aided manufacturing
ERP: Enterprise resource planning
MRP: Materials resource planning
PLM: Product lifecycle management
HVAC: Heat, ventilation and air conditioning
P&ID: Pipe and instrumentation diagram
NC: Numeric control
VR: Virtual reality

1. INTRODUCTION

The great competitiveness in shipbuilding produced several decades ago the first change in the design of outfitting and machinery spaces, making the pre-outfitting of blocks and interim products one of its main drivers.

In most recent times, as a result of harder competitiveness, new circumstances have obliged designers of outfitting and machinery spaces to improve their working procedures, tools, organisation and scope of supply. Thus, material savings, reduction of delivery times, energetic optimisation, environmental protection, automated fabrication and collaborative and remote engineering are nowadays, among others, the main drivers with which the overall design should be performed.

CAD/CAM systems, born with the single task of making easier and more efficient the design and production of ships, have been forced not only to provide solutions to already established requirements, but also to foresee new tendencies and fields for further improvements.

Aspects as embedded calculation tools, flexible data exchange, integration diagrams/3D, rule design, advanced and automatic pipe routing, seamless integration with hull structure and electrical, efficient outputs generation, link with production machines, modularisation of units, links with ERP, MRP and PLM systems and virtual reality are features that CAD/CAM systems should cover for allowing an efficient design of outfitting & machinery spaces.

Although in fact the considerations included in this paper apply to outfitting design in all zones of the vessel, special emphasis is made to machinery spaces, as it is in these zones where the majority of all outfitting components is located and where particularities of outfitting design are most visible.

2. OUTFITTING DESIGN AS PART OF OVERALL DESIGN

2.1 DESIGN PROCESS

Current tendency in shipbuilding for reducing costs and improving delivery times, based on the pre-outfitting of blocks and section to the highest possible level, make compulsory that outfitting design must be fully coordinated with the rest of the design. All aspects of the design become small pieces of the puzzle called vessel, and the fail in one of them could produce the fail in other ones. Moreover, as the earlier stages the fails occur in, the more serious consequences they produce, it is essential to have a complete control of the design.

This control is even more necessary for outfitting design as a result of the modifications that appear during all the stages. Changes consequence of class society comments, shipowner requirements, availability of equipment, production subcontracting, feedback from previous projects, ... are so common that oblige outfitting design to be very efficient in order to comply with estimated cost and delivery time.

2.2 DESIGN COST

Although it varies a lot depending on the type of ship, it is possible to say that, as an average, 50% of the total design cost is related to outfitting tasks (piping, equipment, HVAC ducts, auxiliary structures, ...), 40% is related to hull structure, and the remaining 10% to electrical. With this into account, and assuming a 7-10% of the total price of the ship belonging to design, it results that the cost outfitting design is a 3-5% of the total cost of the ship.

But not only this. An efficient outfitting design means also a good project, and this has direct impact in the cost of the overall construction. Considering that from the total cost of the construction 40% is related to outfitting tasks, we have that the decisions taken during the outfitting design phase have consequences in more than 35% of the total cost of the ship.
So, an efficient outfitting design is an opportunity to dramatically reduce costs and improve productivity. Let’s see how can be achieved this efficient outfitting design.

3. EVOLUTION OF OUTFITTING DESIGN TOOLS

Traditionally, the majority of marine CAD/CAM systems have been mainly focused in hull forms definition, naval architecture calculations and structural design, letting industry oriented CAD/CAM systems to provide suitable solutions for outfitting design.

This general opinion was crumbled when new challenges in shipbuilding, demanding closer interrelations between hull structure and outfitting design, obliged marine suppliers to devote special attention to this latter. As a consequence, some marine CAD/CAM systems (as FORAN) started the development of particular outfitting tools, while others limited their reaction to try to find a closer integration with the existing plant design oriented systems.

Our consideration for developing a particular outfitting design tool in FORAN was based on the fact that the actual requirements for outfitting design are not limited to a close integration with the structural design. Problems to be solved, regulations, working procedures, nomenclature, production information, etc... are so particular of ship design that it is convenient to have a dedicated tool better than try to adapt an existing one.

As time goes by, outfitting tools have been increasing their scope of supply, trying to cover all aspects of outfitting design. As a consequence of this, nowadays outfitting tools use to include (FORAN includes) particular environments for equipment modelling and layout, piping and HVAC ducts routing, definition of auxiliary structures (foundations, gratings, ladders, ...), and definition of distributors supports and hangers. In some cases also electrical and accommodation aspects are considered as outfitting tools.

Particularities of outfitting design require to work in a pure 3D environment and with an amicable and suitable user interface, but new developments in outfitting tools have been always handicapped by the available technology (hardware, graphic possibilities,...). Nowadays it is commonly assumed that outfitting tools should be able to work, at least, in solid visualization method, with huge amount of information on the scene and with a dynamic handling of it (fig. 1)

4. NEEDS AND SOLUTIONS

4.1 INTEGRATION P&ID – 3D MODEL

One of the first stages in the O&MSD is the creation of P&ID’s of all ship systems, being most of them subject to approval by Classification Society. Although the creation of these diagrams could be done in a pure 2D drawing environment (classification societies still require paper copies), it is very convenient to use a tool that allows the early definition of all technological data for pipes, equipment and fittings. In such a way, this information would be available when starting the positioning of equipment and the routing of pipes in the 3D model, thus producing a considerable saving in time. But not only this: it guarantees that all data is consistent and that at any moment both environments (P&ID and 3D model) are in fully correspondence, thus allowing the efficient and quick propagation of changes.

![Image](image_url)

Figure 1: Outfitting data of a 25.000 DWT chemical tanker engine room

Fittings and equipment included in P&ID’s and defined with electric connections should have also the possibility to reference electrical diagrams, thus providing also seamless integration between electric and outfitting design.

This integration P&ID – 3D model should be available in both directions, thus facilitating the creation of as-built P&ID’s with actual information coming from the 3D model and building decisions.

4.2 EQUIPMENT LAY OUT

In parallel with the definition of P&ID’s, O&MSD begins with the lay out of equipment models. CAD/CAM system must provide suitable tools to perform this task in a flexible and rapid way, being convenient to comply with three different requirements:

- It must allow working with preliminary equipment information (almost “reservation space boxes”) that can be refined or changed once more detailed information about equipment is available.
- Equipment lay out must be topological, it means, referred to other existing elements, thus allowing
automatic updates after modifications in decks hull forms,...

- Equipment models must provide the possibility to add data about dismantling spaces and maintenance routes, so from the early stages it could be possible to check eventual interferences.

In order to speed up the process, it must be possible to perform this equipment lay out having as a background not only the existing structure of the ship (up to the level it is completed), but also the moulded lines and surfaces of hull forms, decks and bulkheads.

4.3 ON-LINE INTERFERENCE DETECTION

The generation of 100% valid production information requires an interference-free design, being therefore necessary to have the possibility to detect interferences between all the elements of the 3D model. It is not enough to make this interference detection once the design is completed, but to perform it on-line just as any element is added or modified in the 3D model. Even more, this detection must be done taking into account not only elements visible, but any element stored in the database, including those as insulations, operating spaces, escape routes,.... The system must provide tools to classify the detected interferences (soft or hard), to eventually approve them, and to generate detailed reports. And on top of that, suitable tools must be available for solving interferences detected also in an on-line regime (fig. 2).

**Figure 2: Report on interference, automatically produced as a result of the on-line interference detection option.**

Of course, interference detection algorithms must be optimised in order to do not affect the performance and response time of the system due to the on-line calculation process.

4.4 ADVANCED MODELLING

The most time-consuming part of the outfitting design is the creation of the 3D model including all information for fabrication and assembly. Therefore, it is essential to include in the CAD/CAM system suitable and advanced tools that facilitate the fast creation of the 3D model and its easy modification. This is especially important if we take into account that detail outfitting design is full of repetitive tasks in which automation and dedicated tools are of high importance to save design man hours.

These advanced tools refer both to CAD/CAM general aspects consequence of technological improvements, and to dedicated solutions aimed to solve particular shipdesign aspects.

Among others, we can mention:

- Use of macro commands for repetitive tasks and particular solutions
- Use of parametric elements that can be easily and quickly adapted to particular conditions
- Management of dismantling, maintenance and other reservation spaces for any element of the 3D model
- Importing of equipment data from third party software (formats DXF3D, IGES, STEP, STL, ...)
- Definition and management of outfitting modules for re-use in the same project or in other projects (fig. 3)
- Topological relationship between elements of the 3D model, facilitating propagation of changes
- Easy reconstructions of data after modifications, avoiding manual operations
- Advanced solid mode for routing and edition of lines (pipes, HVAC ducts and cable trays)
- Technologic compatibility, checking of connections between elements (lines, fittings, equipment)
- Smart definition of supports, hangers and auxiliary structures, based on standard solutions and automatically adapted to particular conditions
- Zoning and automatic assignment of elements to geographic zones
- Management of holes and penetrations with embedded approval procedure
- Use of advanced auxiliary geometry options for definition of points, directions, intersections, ...
- Use of advanced visualization options as shading view, transparencies, clipping planes, representation levels, ...

**Figure 3: Forward auxiliary module of submarine S-80**
The main goal is to build a collision-free 3D model within the shortest time, and to have the corresponding data available for drawing generation and for further reuse in the same project or in other project.

4.5 CONCURRENT ENGINEERING

Concurrent engineering concept can be understood under two different aspects: simultaneous design work for different specialities (hull structure, pipe routing, definition of supports,...), and design work by different agents remotely located, being a common practise that these two aspects happen at the same time and in the same project.

The traditional approach of outfitting design starting once the hull structure design is finished, or at least well advanced, is not longer valid. The market demands for shortening delivery times oblige outfitting designers to start their job only with a slight delay from hull structure design, or even at the same time. This means that all information regarding 3D model should be available and accessible just once it is stored in the database. At the same time, outfitting designers must organise their job, allowing the concurrent participation of other designers. Organization by means of zones, systems and combination of both is a common solution for this.

Nowadays, the availability of technological innovations in telecommunications and data transference allows the participation in a single project of remotely located designers. Among the different options available for this, the most common options are the database replication and the remote access to a single database. Both of them have already demonstrated their usefulness, and the selection of one or the other depends much more on communication lines and hardware available in each site.

One key aspect in concurrent engineering is an effective coordination between sites, users, specialities,... In this sense, it is very convenient the use of an access and modification control tool, embedded in the CAD/CAM system, thus guaranteeing that no conflicts would appear. The level of application of this control remains at user criteria.

4.6 CALCULATIONS

Calculations are common in outfitting design during all its stages, and refer to many different aspects: pressure drops, dimensioning of pipes and ducts, flow analysis, heat balance, pipe stress, foundations strength, ... are typical cases of these calculations. The best option is to have the corresponding calculation tools embedded in the CAD/CAM system, not only because data from 3D model are normally the input for the calculations, but also because in some cases the results of the calculations can re-feed 3D model data. However, the availability in most of the cases of dedicated calculation tools makes easier the development of a link between them and the CAD/CAM system. For those links, data transference format should follow international standards, although the particularities of each calculation tool obliges in many cases to work with ad-hoc created interfaces.

Other calculations, with no impact in the definition of the 3D model, as painting surfaces, weights, CoG’s, insulations take-off, ... are included in the CAD/CAM system base on the own data of the 3D model.

4.7 PRODUCTION INFORMATION

During the design process, when creating the 3D model, it is necessary to have into consideration the further fabrication and assembly phases, adapting the design to the actual production methods and devices of the shipyard.

Must be considered, among others:
- Maximum length for pipes considering the straight pipes supplied to the shipyard
- Handling of fixed angles for elbows, for optimization of materials
- Bending machines and restrictions for bending of pipes (clamping, collisions, allowable nominal diameters, ...) (fig. 4)
- Size of galvanizing and other treatments pots for pipes
- Availability of automatic flange welding machine
- Gross plates used for development of HVAC ducts
- Standard plates and profiles used in Auxiliary Structures
- Use of standard support and hangers

Figure 4: Automatic bending checking when routing pipes in FORAN System

Additionally, it is necessary to complete the production oriented design assigning outfitting elements to interim products, reproducing the actual build strategy according
to which the ship would be built and allowing the pre-
outfitting of blocks and sections.

But it is not enough the creation of a 3D model having
into consideration those aspects: it is necessary that all
production and assembly information is generated in the
most automatic way and avoiding manual operations.
Moreover, due to the common modifications that appear
during the design process, the system must maintain an
automatic control of the production information and the
3D model, providing warnings when the changes affect
already generated production information.

CAD/CAM system must provide NC data for feeding
machines and devices of the shipyard as bending
machines, welding machines, ... thus being necessary to
customise formats in order to match every shipyard own
machines.

4.8 LINK WITH THIRD PARTY SOFTWARE

CAD/CAM system must handle of the information
necessary for creating a collision-free design and for
generating all production and assembly information, but
not only this. This 3D model information is at the same
time necessary for other activities and other departments
involved in the construction of the ship, as planning,
purchasing, subcontracting, accounting,... With this in
consideration, it should be possible to export 3D model
information to other systems as ERP, MRP, PLM and others.

Even restricted to design tasks, it is very common that
several design agents collaborate in the same project, so
it is necessary that 3D model information should be
shared between them, to serve as reference. The
paradigm of this problem appears in case two or more
design agents collaborating in the same project use
different CAD/CAM tools. In such a case the CAD/CAM
systems shall provide data exchange between them
(heterogeneous design in context) leading to different
degrees of integration like visualization, spatial
integration and cross manufacturing, depending on the
characteristics and amount of 3D model information to
transfer. At least, it should be geometry and key
attributes.

Formats for transference of data are not fixed, and
despite the existence of recognised international
standards, in most of the cases the most extended practise
is to have dedicated formats, or particular adaptations
from standard ones.

Transference of 3D model information could produce
loss of performance due to different geometrical
approaches to represent elements in both CAD/CAM
systems. In this case, special solutions must be adopted
in order to minimise this impact.

4.9 VIRTUAL REALITY

VR tools are currently not only separated tools for
checking an existing design, but actual design tools
completely imbricated in the design and production
processes. With their use, all agents involved in the
construction of a ship can take decisions that affect the
design itself, and at the same time check if previous
decisions are in correspondence with previously stated
requirements (fig. 5).

Options included in VR tools are, among others:

- Interactive navigation through the 3D model with
different navigation modes
- Handling of very large 3D models
- Selection of objects or group of objects (according to
build strategy) and display of technological and
graphical attributes
- Marking-up of objects and addition of commentaries
for further navigations or modifications in the 3D
model;
- Calculation of ship coordinates, distances, angles,
clearances between objects, ...
- Illumination of 3D model according to actual
luminance on board
- Assignment of textures, colours and transparencies to
objects
- Collisions checking
- Deletion and invisibility of objects or group of
objects
- Movement of objects and group of objects (linear and
rotations)
- Handling of human models and checking of
ergonomics
- Simulations of escape routes and dismantling routes
of equipment
- Simulation of fire & smoke conditions
- Creation, storing and reproduction of trajectories
- Generation of video files

Figure 5: Navigation through outfitting 3D model of an
AHTS vessel
Additionally, modern technologies allow the use of VR tools with stereoscopy and tracking options, and their adaptation to complex environments for total immersion, with six-plane projection and use of helmet, gloves and other advanced VR devices.

4.10 RE-USE OF INFORMATION

In shipbuilding, normally only few units of a particular project are actually constructed (very common even only one), and due to this shipyards and design agents try to re-use as maximum as possible from previous projects.

In the case of outfitting, it is a traditional practise to re-use data regarding standards, materials, specifications, equipment models, ... and the CAD/CAM system has enough tools for achieving this. But in some occasions complete or partial outfitting designs are valid to be used in further projects, and the CAD/CAM system should have suitable tools for performing it. Data must be transferred by system, by zone, by module, by skid and even by interim product, at user decision, including attributes, geometry and layout. Transferred data could be handled in the new project as any other data defined directly on it, capable of modifications and updates.

Current tendency of modularisation of outfitting design and build makes more useful the re-use of data, not only from a single previous project, but from several ones.

5. ... AND BEYOND

5.1 RULE-BASED DESIGN

Rule-based design intends to help designers to adopt solutions that have been previously tested and are of common practise in the shipyard. With this, the possibilities of a mistake by the designer are dramatically reduced, thus making the design consistent and robust but without increasing the time need to complete it. In the case of outfitting this does not refer only to fulfilment of regulations of Class Societies or other regulatory body (as it is the case mainly of hull structure), but to fulfilment of rules in the widest sense of the concept.

These rules are closely related to production particularities of each shipyard, and cover different aspects as:

- Typical technical and constructive solutions
- Lay out and routing restrictions according to regulations or calculations
- Automatic assignment of attributes
- Material optimization
- Compatibility of elements
- Solving of conflicts

For obtaining as much benefit as possible, rule-based design options should work in an on-line regime, although it is also convenient to have batch tools that allow checking completed designs before production information is generated.

As each shipyard has its own solutions and criteria, rules to be fulfilled and their parameters should be programmed by the user and eventually modified according to particular circumstances.

5.2 AUTOMATIC ROUTING

One of the most time-consuming tasks in outfitting design is the routing of pipes, HVAC ducts and cable trays. In order to minimise this time, but without reducing the robustness of the design, automatic routing options are the best solution (fig. 6).

Figure 6: Cargo heating coils of an oil tanker barge designed with automatic routing tools

These automatic routing options should provide simple solutions, with minimum lengths and optimisation of material, something that is not difficult and several algorithms already cover (Lee, Dijkstra, ...). But the matter is not only to consider existing elements for future routings; it is also necessary to assign priorities, and eventually provoke modifications of existing elements as a consequence of new ones. The complexity of the problem means that there is not yet a suitable solution for the automatic routing, and the solutions provided by CAD/CAM systems can be understood only as partial ones, at least for ship design.

6. CONCLUSIONS

Outfitting design is one of the most complex aspects of shipdesign, having great impact in the construction of the ship, and in its overall cost. Due to this, the most efficient the outfitting design is, the biggest savings will be obtained.

SENER, in its double role as shipdesign and software development company, has embedded into FORAN all the experience accumulated during more than 50 years, converting FORAN System in a suitable tool for solving outfitting design needs, and allowing outfitting design agents to improve their efficiency and reduce costs and delivery times.
At the same time, FORAN continues to be improved, providing solutions to new trends and challenges of outfitting design.

7. REFERENCES


8. AUTHORS’ BIOGRAPHIES

**Rafael de Góngora** holds the current position of FORAN Product Manager at SENER. He is responsible for the new developments of FORAN System. In the past, he worked in the ship design office of SENER as design engineer (especially in outfitting), and project engineer. During some years, he worked also as FORAN sales manager for East Europe.