A unique application and point of truth for Naval Architecture Calculations

Verónica Alonso, verónica.alonso@sener.es, SENER (Spain)
Rodrigo Perez, rodrigo.fernandez@sener.es, SENER (Spain)

Many tools handle with the calculation of compartment definition, hydrostatics, intact and damage stability and power prediction, but these calculations are separated from the rest of ship CAD/CAM tools. Ship designers need to work closely with the shipyards, in a complex and distributed environment making necessary to have suitable tools at early design stages to ensure profitable projects.

Naval architecture is handled in FORAN with a revolutionary approach, where integration and advanced features are the relevant characteristics in a single and complete set of applications that are used in conjunction to other disciplines, from concept design to operation. This new approach groups the former modules for naval architecture available in FORAN from many years, is intuitive and user-friendly. The information is stored in a database instead of a wide set of files. As regards this feature, there are two different alternatives depending on the scope of the project. If the ship designer wants to calculate only naval architecture calculations, the solutions is based on a SQLITE database suitable for a standalone application. This approach benefits a ship design office, in the study of different design alternatives very quickly but having a complete control of them. The other option is integrating the Naval Architecture with the rest of FORAN design disciplines, in a single database based in Oracle. In this case, the great benefit comes from the single truth of data from concept design to operation, which ensures dramatically the reduction of errors and re-work.

After the definition of compartments in 3D, by using a very fast application, the module guides the user through the naval architecture calculations with a tree of elements very intuitive, with powerful key algorithms and with a solid representation of spaces. The definition of the necessary entities to make any kind of calculation is very fast.

For the intact stability a set of standard stability criteria is provided. It is based in a quick definition of loading conditions, initial situations, flooding conditions and compartment subdivisions. And for the evaluation of the damage stability a set of standard stability criteria are also provided, following deterministic and probabilistic approaches. With these tools any naval architect is able to make very fast all the necessary studies to assure the stability regulations are complied with.

KEY WORDS: Ship design, Shipbuilding CAD Systems, Naval Architecture.

NOMENCLATURE

CAD Computer Aided Design.
Cp Prismatic coefficient
Cb Block coefficient
FGA FORAN general Arrangement
GM Permissible metacentric height (m).
GZ Righting arm (m).
HCB Height center of buoyancy
IMO International Maritime Organization.
KG Permissible height of the center of gravity (m).
NURBS Non Uniform rational B Splines
MSC Maritime Safety Committee.
SOLAS International Convention for the Safety of Life at Sea.
XCB Longitudinal center of buoyancy
XCB A Longitudinal center of buoyancy with appendages
ZBM Transverse metacentric radius

INTRODUCTION TO THE NAVAL ARCHITECTURE CALCULATION

It is necessary to go back to the XVIII century to find the first treatise of naval architecture. Pierre Bouguer (1698–1758) was a French mathematician who is known as the father of naval architecture. In 1746 he published the first treatise of naval architecture, Traité du navire, which among other achievements first explained the use of the metacentre as a measure of ships’ stability. His later writings were nearly all upon the theory of navigation and naval architecture.

Also it is possible to track the history of the naval architecture calculations programs, following the history of the shipbuilding CAD Systems. The shipbuilding CAD Systems help to the Marine/Naval Industry in the design and construction of ships, boats and offshore platforms. Some authors mention that the birth of CAD Systems was 350 BC, with the mathematician Euclid of Alexandria. Many of the postulates and axioms used by these CAD Systems are based on Euclidean geometry.

If a story line continues, there is no return to innovate in these areas, up to 2300 years after the death of Euclid, where the concept of CAD defined and linked first to computers.

Most authors give as inventor of CAD Systems French engineer Pierre Bezier at the School of Arts et Métiers ParisTech Engineers. This engineer developed the fundamental principles of CAD Systems with the program UNISURF in 1966. Since then, CAD Systems have been introduced in academic, university, companies as well as government sectors.

The real breakthrough in CAD Systems came under the development of computers, and it is at the beginning of 1970’s when the use of the shipbuilding CAD Systems becomes popular.
in the shipbuilding industry. The increased use of more powerful and easy to use computers and workstations, have facilitated in the development of more intelligent shipbuilding CAD Systems as well as their use in day to day engineering worldwide.

The first tools to evaluate damage stability were developed around 1970’s. The FORAN shipbuilding CAD System, created in 1965, included in 1977 a new tool for evaluating flooding conditions and damage stability for defined loading conditions, called F.6/4 (see figure 1). Later on, the name of the damage stability module changed to FLOOD, to become FBASIC right now.

The history of FORAN tracks the naval architecture calculation used worldwide. After a new criteria is used in the ship design, FORAN incorporates/implements the criteria on the System. As example, the latest probabilistic regulations applicable to cargo, ferries and passenger ships.

The introduction of naval architecture calculation in FORAN, allowed SENER to license the System to some world class shipyards showed in the table 1 below.

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<th>Year</th>
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<td>1974</td>
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Table 1. Some leading shipyard FORAN references in the 1970’s and early eighties

THE ROLE OF A NAVAL ARCHITECT DESIGNING A SHIP IN A COMPLEX SHIP DESIGN AND PRODUCTION ENVIRONMENT

Naval Architects are using the same principles for ship design from centuries. From the most simple trial and error to the application of physical equations, the towing tank, the implementation of the powerful computing systems, or even the study of root causes after a sinking, the truth is that every of this aspects are still involved in the analysis.

The challenge comes from ensuring the best ship design project-addressing the most demanding characteristics- but with the added pressure of developing the project in a high competitive environment, where the time and the money have something to say. The importance of using the most advanced technologies available for ship design and naval architecture takes more relevance, and how are they integrated with the rest of design stages is critical.

Naval Architects take part in some ways in every stage of the design and production although it is at the beginning of the project where they give most part of their participation, but the project is alive during the whole ship design, production and lifecycle. The accurate and quality of a ship project is transferred downstream into profitable production and operation, less errors and savings.

NAVAL ARCHITECTURE WITHIN THE COMPLETE SHIP DESIGN AND PRODUCTION PROCESS

Naval architecture is a key part within the complete ship design and production activities. Regarding the tools applied in this important task, they are usually quite disconnected from the rest of design tools. The typical iterations and design revisions at this stages are done in a workflow that requires a lot of effort. And, which is worse, many people could be working in the same project with the potential risk of introducing errors because of the management of information in files. Downstream is even worse, because the detail design stage usually starts with the generation of another 3D model of the vessel.

So, the challenge is having an integrated naval architecture tool with the rest of design disciplines to improve the quality of the design, to ensure the single truth of data and to avoid errors and rework.

SENER develops a shipbuilding oriented CAD/CAM system since 1963. Starting as a mathematical tool for the generation of hull forms, FORAN (Acronym of Analytical Forms in Spanish) has grown and evolve during the years to be a complete set of solutions for the ship design and production, from concept design to operation.
Below there is a description of Based in a modular approach, in FORAN the Initial/Basic Design process is handle as it is described below.

**Hull forms definition**
Traditionally, the hull forms generation are based in mathematical formula, that with some input data generate a preliminary hull forms which were a set of curves. FORAN currently generates the hull forms based on NURBS and offers advance capabilities for the transformation of forms generated in a third party software. The hull forms are stored in the database too.

**General arrangement definition**
Once the Hull forms are settled, the definition of spaces and compartments is done in a new module in FORAN with a hybrid approach in 2D & 3D. Naval Architects can study different design alternatives easily, while the definition itself is very intuitive. The clear advantage of using this approach for the general arrangement definition, with all the information generated in a 3D model since the very beginning, is the data consistency. As everything is stored in the database, all people ensures the access to the same data at the same time, no matter where they are located (in different locations, companies or countries) which is another benefit. Other relevant improvement is the accurate estimations (weights, material, capacity, etc.) that is crucial for a better design. Maybe the time consumed in the general arrangement definition in 3D is higher than in the traditional approach in 2D; but the savings achieved only in the appropriate estimation of material or avoiding costly errors in production are for sure much more relevant. The transition to further stages, whether for the naval architecture calculations or later for the detail design stage and production is smooth and direct in FORAN.

**Naval architecture calculations**
FBASIC is the new FORAN module for the naval architecture calculations, storing the data results in a single database and with the same interface. It starts with the spaces already generated in FGA.

The transition between the former solutions in FORAN is huge, in particular in the amount of data that can handle and in the interface. FBASIC ensures a proper definition of a ship design project in a very easy and intuitive way, based on definition trees (entities, calculations and stability).

FBASIC is based in a set of functions to handle the definition of some necessary entities related with the calculations, the calculation of hydrostatics and the stability studies, both under deterministic and probabilistic approaches. It is remarkable the aid of advance features to handle calculations and generating huge amount of data very fast. This optimizes the naval architecture, studies, and allows them to perform more accurate analysis in less time.

The implementation of changes in the ship after some results coming from the calculations are performed easily thanks to the process itself, based on 3D.

**Transition to detail design and production stages**
Once the calculations ensure that the project is suitable and complies with regulations and safety criteria, the process continue through the basic design and detail design stages and production. The transition in FORAN is direct, smooth. The generation of a preliminary structure 3D model starts by including the necessary data at this stage, and later is populated with more attributes for production.

In outfitting the process is similar and totally integrated with the structure; during the basic design stage FORAN handles intelligent P&I and single wire diagrams which are connected later with the 3D model. The definition of the complete 3D model of equipment, pipes, HVAC, auxiliary structures and supports are based on automatic tasks with relevant aids such as the on-line clash detection, as an example. The same approach performs the design of electrical and electronics. The ship design project is alive during the overall process, because even at this stage some characteristics of the vessel could change, and some calculations could be needed.

**Operation**
During the ship operation the advantage of having a single 3D model of the vessel is remarkable. The need to perform overhauls, transformations, to study cargo situations or for studying possible repairs make more and more crucial to have generated before a complete and integrated ship design project in the appropriate tool.

In particular, it is worth to mention that naval architecture calculations are specifically relevant within a naval shipbuilding, where the study of compartments, stability and damage stability is very important during the design and lifecycle.

**NAVAL ARCHITECTURE IN FORAN: FBASIC**
Assuming that the aid of computer Systems has been great for managing the calculations, giving more time for innovation and analyzing, we can’t avoid their limitations, as only a qualified naval architects with knowledge about the fundamental theories could recognize the results and manage them properly. FORAN incorporates a new group of capabilities in FBASIC, to manage the naval architecture, and help the naval architects during the development of studies and analysis, improves the time...
for the calculations and presents the results in very intuitive manner.
FBASIC has two options for storing the data. One is in the FORAN Oracle database, in case the naval architecture is a part of a complete project of design and production. Or could be used separately with a SQLITE database.
As a result, with the aid of this tool the naval architect can reduce considerably the effort during this task.
Below it is described the complete capability of FBASIC.

**Watertight definitions**
The geometrical information about the hull comes from the FGA module in FORAN (the spaces) or from FSURF (the hull forms). The limits of the watertight hull, which needs to be a closed solid, is generated simply by the external hull and a certain height, by some decks and heights or even considering some spaces already generated in FGA.
There are some particular spaces that modifies the displacement, such as negative spaces, appendages, spaces increasing the displacements and hatches.
The transverse sections are generated automatically and can be recalculated after changes, with the possibility for the generation of sections by the user, which will be highlighted in the graphical area.

**Appendages**
In FBASIC it is possible to define appendages, which are an estimation of volume and center of gravity. For a more accurate appendage definition, they need to be defined previously in FGA, and then will be considered as part of the watertight hull and will be taken into account for hydrostatics and stability.

**Propellers, rudders and other appendages**
Propellers and rudders can be defined too, based on their dimensions to calculate the volume, or given the volume itself. They will be considered for the calculations.
Other appendages are not considered for the displacement but will be taken into account for the calculation of the minimum draught in loading conditions.

**Draught marks and margin lines**
Draught marks are defined along the length of the ship. In the other hand, margin lines will be used as references for damage stability calculations and will be set by a distance from a deck or by a point list.

**Opening and connections**
Internal openings are defined in FBASIC To be used in the management of flooded compartments under a damage condition. External openings will affect the equilibrium and stability calculation. There will be three types, to be used as a reference point, as a protected opening with watertight close or permanent unprotected openings.

External openings should have a space associated from the space tree, and under a damage condition of this space, the opening will not be considering in the stability calculation.
Internal opening connecting two spaces will be active under a damage condition if just one space is affected.

**Lightship weight distribution**
The weight distribution has been always a key point in the naval architecture calculations, see figure 2.

![Figure 2. 1980’s weight distribution in FORAN System](image)

Two types of distribution can be defined. The complex distribution is based on weights that can be grouped a will form a tree structure, being possible to estimate any value or use a regression from a customer existing database. Weight items are represented by a linear distribution, which will be used for the longitudinal strength calculation. A spreadsheet is used to edit the weights and some information such as CoG and limits of the distribution weight.
On the other hand, the continuous weight distribution refers to the estimation of the steel based on the Lloyd’s Register that use weights as construction frames.
FBASIC counts with an estimation tool for a selected value.

**Wave profiles and wind profile**
The wave profile, defined as sinusoidal or trochoidal, is used in the cross curves of stability and in the loading condition calculations.
The wind profile can be generated interactively by a set of points, by a list of points or can be imported. They will be used for the stability criteria including heeling moment calculations.

**Sounding lines**
Sounding line tables are generated by a polyline associated to each space, defined by the coordinates of each point, the increment (auxiliary readings) respecting the previous point and the discount volume.
Sections
The definition of multi sections according with the main three directions-transversal, longitudinal and horizontal- will allow the subdivision of compartments for the probabilistic damage stability calculations.

Modular cargo
The modular cargo aids in the definition of loading conditions, and refers to container cargo but also to group of car and trucks, giving the coordinates, weights and center of gravities. Container arrangement is a combination of several groups of containers.

Exposed surfaces
These surfaces will be considered in the heeling calculation due to wind.

Layouts
The possibility to set different layouts with different sections to be used in the loading conditions reports, when loading spaces drawing are selected, improves the presentation of results.

Admissible bending moments and shearing forces curves
The definition of admissible bending moments and shearing forces curves for the longitudinal strength calculation.

WATERTIGHT CALCULATIONS

Parallel hydrostatic calculations
FBASIC calculates the following hydrostatic coefficients:
- Displacement in tones, of the watertight hull up to the draught required
- Molded volume taking into account negative spaces
- XCB: Longitudinal center of buoyancy, considering negative spaces
- XCBA: Longitudinal center of buoyancy, considering negative spaces and with appendages modifying the buoyancy
- HCB: High of center of buoyancy
- Waterline area
- Maximum transversal section area
- ZBM: Transverse metacentric radius
- Longitudinal metacentric radius
- Cp: Prismatic coefficient
- Cb: Block coefficient
- Cm: Maximum section coefficient
- Moment to trim 1 cm
- Tons per cm of immersion
- Wetted surface
- Waterline coefficient
- Longitudinal center of gravity of the waterline

In a very intuitive way, the naval architect can introduce the necessary input data such as draughts, trims, heel angle or even non-plane waterlines (parabolic or polynomial).

Once the calculation process has finished, the results are displayed in a clear table accompanied by a graphic of each coefficient selected on the table. All results are stored in the FORAN database and can be recalculated after a change in the input data, being possible to print and to export them to MS Excel. The user can decide which coefficients to be included in the report and change the units.

Several hydrostatic drawing can be saved and stored in different formats in a specific node.
- Sectional areas curve drawing
- Bonjean Curves
- Deadweight scale
- Trim diagram

Cross Curves
Cross curves are calculated in F BASIC for a different heel angles, trims and displacements, depending on each calculation. The outputs are the center of buoyancy and KN values for different heel angles and trims, and maximum displacement up to the immersion of the edge of a deck for each heeling angle, and finally the maximum displacement until the immersion of each opening.

A complete plot and customized reports of these curves and results are generated.

Flooding analysis
Naval architects will check two different effects: the liquid load diagram, to know the variation of the heel angle due to the filling of tanks, and second, the diagram of flooding effects, calculating in this case the transverse moment and changes in the GM due to the percentage of filling of tanks, for liquid loads only.

The permeability is considered by defect or can be defined too.

STABILITY STUDIES
FBASIC ensures the highest accuracy to perform the needed stability studies, combining features with power of calculation with an easy-to-use interface that guides the naval architect.

A stability tree will contain all data in relation with the different studies, grouped in different nodes. In order to ensure the appropriate perform of analysis, some locking possibilities are given.

Stability criteria
The System provides a standard stability criteria while different user stability criteria can be added easily.

Standard stability criteria can be added or copied between projects. The standard stability criteria includes:
- IS Code 2008 General
- IS Code 2008 General Reduced
- IS Code 2008 Weather
- IS 2008 Pass
- IS 2008 Pontoons
• HSC2000 code monohulls
• HSC2000 code multihulls
• DDS-079 Wind
• DDS-079 Lift
• DDS-079 Towline pull
• DDS-079 Crowding
• DDS-079 Turn
• BV Naval General
• BV Naval wind Bureau Veritas
• BV Naval General Ice
• BV Naval Turn
• BV Naval Lift
• BV Naval Crowding
• BV Naval Wind and Crowd

The user stability criteria is based on a set of stability variables that need to comply with a certain value, as per example:
• Initial corrected metacentric value at equilibrium
• Equilibrium heel angle
• Angle of maximum GZ
• Range of positive GZ from the equilibrium heel up to the second intersection of the GZ curve with the X axis
• Deck immersion angle
• Intersection with heeling lever
• Range of residual GZ between two angles
• GZ at a given angle
• Dynamic stability in a given range (between two angles)
• Residual stability (as the difference between area below GZ curve and area below Heeling lever curve)
• Difference of residual areas (The first area is between the heeling lever curve and GZ curve from a fixed angle minus a range, and the first intersection between curves. The second area is the area between the GZ curve and Heeling lever curve from the first intersection between curves up to the second intersection or a fixed angle)
• Ratio between residual areas
• Ratio between dynamic stability and area below HL
• Ratio between residual stability and dynamic stability

FBASIC contains mathematical formulations with curves or variables defined to be used in any stability criteria defined by the user. New parameters can be added to the list.

Loading conditions
A node contains the list of loading conditions defined, being possible to see in a very intuitive way which ones has been already calculated for the equilibrium. It is possible to edit or multi select some loading conditions. Stability, longitudinal strength and evaluation of stability criteria is the objective of this part of the system, for the selected loading conditions.

The edition of the loading condition is made in a very user-friendly window far away from the old views used in the past for this purpose. In order to view the results, a report is generated with a loading condition already calculated.

The main data that needs to be filled, includes values such as lightship weight, openings, wind profile, wave profile, middle draught calculation, group of loads, and stability criteria for running the calculations. If any of these values is not included, the program will use the ones set by default in the Entities tree described before. It is interesting the advanced management of group of loads. The following loads are handled:
• Loads in spaces (tanks)
• Local loads
• Modular loads
• Group of containers
• Arrangement of containers

One of the advantage of the new visualization is the window displaying the summary of the equilibrium results of the loading condition edited. After the addition of a new load (in a tank or modular one), the displacement and coordinates of center of gravity are automatically updated.

The visualization in 2D of the compartments of the ship loaded in different color, for each loading condition, is very useful, because it is possible to visualize unselected spaces and damage spaces too. Different sections and views (longitudinal, transverse, plan) can be displayed as well, and a section of aft perpendicular. The possibility of selecting interactively spaces in a section is another advantage.

The results preview includes:
• Stability curve (righting arms curve, heeling lever, and progressive flooding angle if a set of openings have been selected).
• Stability table with the numeric results of the righting arms curve; for every heel angle in the intact options and the equilibrium angle, shows GZ arm calculated, dynamic stability value, trim and correction.
• Stability criteria: results under the evaluation of a criteria. A green light indicates that the criteria is complied. Red light means that at least one atomic criteria is not fulfilled.
• LS curves: drawings with the bending moment and shearing forces curves.

Initial situations
Initial situation is the intact data before the damage and can be defined by:
• Aft and fore draught and the height of center of gravity. Every data can be edited, including draughts, height of center of gravity, list of openings, wind profile and margin line.
• A previous loading condition, considering the filling of tanks for free surface effects and exchange between cargo and sea water under damaged compartments. Every data can be modified except the fore and aft draughts, as they are a consequence to the equilibrium already calculated. Wind profile, openings can be selected from the loading condition while the margin line must be selected manually.
FBASIC allows the generation of new initial situations easily, and can create automatically as many initial conditions as loading conditions already defined.

**Damage**

A flooding condition is defined with a list of damaged spaces from the tree of spaces that have been previously defined in FGA, without negative spaces. Damage cases can be group in nodes and sub-nodes. FBASIC gives the user a quick tool to generate damages according to damage penetration dimension, with the aid of a box created by transversal, longitudinal and height that can be moved longitudinally and transversally with the bottom of the box always in Z coordinate in zero position. With this box it is possible to create many damage cases. In addition, it is possible to take the predefined damage penetrations from MARPOL Regulation or SOLAS 2009 II-1 Reg. 9, part 8-2. Freeboard calculations must be performed before getting the values. The possibility to generate drawings representing the damage zone of the ship is very useful, with several sections and predefined views, being an option the generation of a report with several damage cases and a list of damaged spaces, permeability and intermediate stages of flooding. In case of water on deck calculation additional data is required, as the space with the water on deck (selected from the list of spaces) and aft and fore limits of the damage. Minimum freeboard will be calculated as well in the evaluation of SOLAS 90 damage criteria and water on deck. The list of damaged spaces can be created selecting them from the tree of spaces or by graphical selection in 2D sections. Additional data to be defined will be:

- Permeability (%)
- Initial filling (%)
- Initial density (in order to calculate the weight of the cargo liquid to be spilled in the flooding case)
- Initial Stage (in case of intermediate stages)
- Total Stage (set the number of steps to consider a full damage)

The graphical selection helps the naval architect with 2D views for the visualization damage spaces, with the possibility to select or unselect spaces interactively.

**Floodings**

With the combination of an initial situation and a damage condition, a flooding case is generated, with the aim of calculating equilibrium, transverse stability and evaluation of damage stability criteria. All the different flooding cases are listed in a node. Automatically it is generated a view displaying a summary of the flooding results with information about equilibrium, stability, flooded spaces, openings and evaluation of stability criteria. A transverse and profile 2D view show the flooded spaces and the equilibrium line.

**Maximum KG calculations**

In both cases, intact stability and damage stability it is possible to perform the maximum KG calculations (or minimum GM), taking in consideration a set of draughts, a specific loading condition and for flooding cases too. A diagram shows the results, with the possibility to represent several calculations in a single chart by dragging and drop another calculations from the corresponding nodes (loading conditions, flooding conditions, etc.). In this case, if the KG obtained is higher than the KG originally represented, it will appear in red color.

![Figure 3. KG maximum Diagram](image)

The representation allows to switch between maximum KG and minimum GM. Reports can be generated automatically as well, in different formats. One of the most relevant calculation is to determine the maximum KG complying the selected stability criteria. To facilitate the checking of the different situations against the limit curves of KG, a visual tool is provided where the naval architect can plot the different limiting curves and to drag and drop the KG values of the initial situation (see figure 3).

**Probabilistic regulations**

One of the more interesting features is the possibility of automatically generating damage cases just selecting the extension of the damage. The program will travel along the ship generating damage cases with damaged spaces. The program allow to set the extension of the damage individually or by taking into account MARPOL or SOLAS II-1 Regulation 9 and Paragraph 8-2 or a generic one (see figure 4).
Due to the heavy computation requirements for this complex calculation, the application uses the multithreading capabilities of the computer.

Initial situations and damage cases are combined automatically to create flooding conditions to be studied. The program provides a very easy and intuitive method to create subdivisions. The subdivisions are created by transversal, longitudinal and horizontal sections. A wide variety of methods to enter data for subdivisions is available. With the sections defined the naval architect has a very easy and quick method to create the subdivisions, as it is shown in figure 5.

For preliminary calculations it is possible to automatically generate spaces from defined subdivisions. When the compartment definition is consolidated, the subdivision will use the compartment definition. The program displays the status of the calculation with a color code indicating the degree of compliance of the selected stability criteria status, as it is shown in figure 6.

The subdivision is made up of different zones and subzones that are very easily edited and displayed as it can be shown in the figure 7.

By using 2D views it is possible not only visualize damage spaces but it is possible select and unselect spaces. To select the sections to be displayed click on the left and lower side of each view with the left button of the mouse:

- Centre button of the mouse will reset the three views displaying a longitudinal view (in grey color is view, not a section), a horizontal view (in grey color, not a section) and a section at aft perpendicular.
- Profile view: Clicking on near the left side of the view will change the horizontal section displayed. Clicking on near the lower side of the view will change the transverse section displayed.
- Transverse view: Clicking on near the left side of the view will change the horizontal section displayed. Clicking on near the lower side of the view will change the longitudinal section displayed.
- Plan view: Clicking on near the left side of the view will change the longitudinal section displayed. Clicking on near the lower side of the view will change the transverse section displayed.

The accomplishment of the different regulations can be easily evaluated with the diagram shown in figure 8.
For all the calculations, an entire collection of documents with drawings are automatically generated in FORAN Document System from which they can be exported to Microsoft Office Suite and PDF formats.

All the tools will allow the different naval architects to perform a complete probabilistic study including the maximization of the attained index $A$.

CONCLUSIONS

Next steps in the software development will be the calculation of the longitudinal strength after damage to know the situation after grounding, collision, etc.

Also the calculation of damage under wave conditions will be available very soon within FORAN.

One of the features currently under development is the calculation of the effect of the cross flooding pipes between compartments. The application will be able to calculate the effect of the flooding of some compartments including the connection among them. This will allow not only to have a more realistic knowledge of the behavior of the vessel after the damage but also to identify actions to get equalization of the ship by flooding opposed compartments. These calculations will also include equalization time, etc.

Future versions of these tools will incorporate the analysis of dynamic behavior of the damaged ship in order to know the response of the ship to special sea conditions. The application will also be able to predict the ship behavior under corrective actions by the master, so supporting him about how to deal in a damage, what kind of actions would delay the capsizing, or even would avoid it.

As a summary, there are suggested several scenarios to improve the naval architecture calculations for the next years. Some of these improvements seem to be unreal or very difficult in the short term, but reality often exceeds expectations in any field, and probably more in the technology. The proposed innovations and research of these damage stability tools offer a hopeful future.

REFERENCES

1. RAWSON, JK and TUPPER, EC. Basic ship theory. 2001
4. PEREZ, R., ‘Estudio de la adecuación y suficiencia de los “KG’s” límites para el cumplimiento de los criterios de estabilidad en los diversos campos, para los buques de carga rodada (mercantes-militares)’, 48º Congreso de Ingeniería Naval e Industria Maritima, 2009, Vigo, Spain.