# Direct BREP Solid Integration: A Step towards Virtual Ship's High Resolution Stability

**M Pommellet,** Sistre, Greece - France

**SUMMARY**

As long as ship's master model was a hand-drawn lines plan, the hydrostatic and stability calculations were based on 2D lines integration.

The computerization of this process has then simply consisted in transcribing this manual process by modeling the ship lines, allowing to speed-up the calculations and to process quickly heavier ship models.

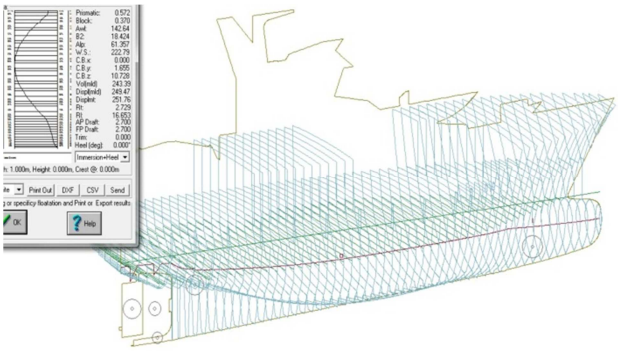
But finally, following to computer's growing power and affordability, the traditional lines plans have been gradually replaced by 3D surface models, so that most of today's hulls are now designed and faired as 3D surface models.

Although the common sense shows that compartments and tanks are solids by nature, this deep mutation of the hull design process hasn't yet brought many changes in the field of hydrostatic and stability calculations, which still remains, most often, a line process, in which the surface → lines conversion introduces significant time, interactivity and accuracy wastes.

The goal of this paper is therefore to discuss the benefits of direct BREP solid integration in the ship design process, thanks to our experience in developing MAAT Hydro, Sistre's new hydrostatic solver.

## 1. CLASSICAL (STATIONS BASED) HYDROSTATIC CALCULATION

As an introduction, let us recall shortly the classical way to carry out the hydrostatic and stability calculations, in which float's geometry is represented by a set of stations, corresponding to ship's hand drawn lines:



Most often, these lines are simply closed / planar polygons, whose immersed area under any floatation plane can be easily calculated by the trapezoidal rule. These polygonal descriptors can be easily obtained by:

- Digitizing existing body plans (but a significant accuracy loss may result from poor quality plans as well as from a too rough acquisition)
- Importing a table of offsets (but numerous offsets may be necessary for getting accurate results).
- Evaluating NURBS descriptors (but Gauss method allows integrating NURBS directly and accurately).

As soon as station's beams of waterline, immersed areas and girths are integrated for a given floatation, Sectional Area Curve, floatation and hull's data can be easily obtained.

Multiple compartments and tanks can also be easily represented by this proceeding, but it must be recalled that the transverse subdivision of such models can only operate on an existing station.

Let us also mention that, as shown below, this proceeding doesn't allow calculating the wetted surface area accurately, which may slightly influence the plate thickness displacement corrections.

## 2. DIRECT BREP (SOLID BASED) HYDROSTATIC CALCULATION

3D surface and solid modeling have now become a hull design standard and updating the hydrostatic analysis algorithms accordingly now seems to be an urgent need: Why continuing to waste time and accuracy for converting high level ship models into stations while their direct process is now possible ?

Obviously, any buoyant object is, first of all, a closed (i.e. watertight) set of faces and can, therefore, be represented by a BREP solid (i.e. a Boundary REPresentation solid), which is, nowadays, a well-known 3D modeling standard, handled by almost any 3D modeler.

In such a BREP solid, each boundary is defined as a trimmed NURBS.

*© 2013: The Royal Institution of Naval Architects*

A trimmed NURBS, consists in a plain NURBS surface (materialized by its iso-parametric network) 'owning' a set of bound closed trimming curves defining face's 'real' boundaries (represented by the solid outlines).

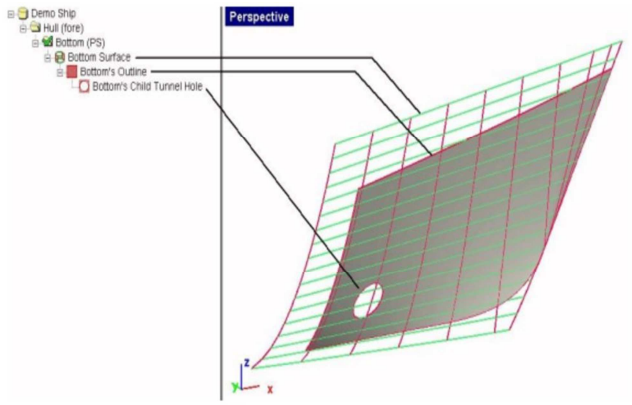



Figure 1: A BREP Solid Boundary is a trimmed NURBS

A BREP solid is, therefore, simply represented by a closed (i.e. watertight) set of trimmed NURBS:

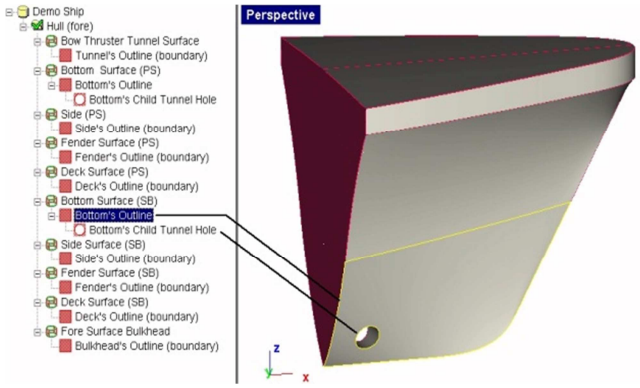



Figure 2: A BREP Solid is a closed set of trimmed NURBS

When all these faces can be gathered into a single BREP solid, a special attention still has to be paid to their orientation: As each face has two sides (let's say a wet–outer and a dry–inner side), these sides have to be correlated in order to avoid accounting reversed pressures in float's total buoyancy.

When float's boundaries are gathered in such a watertight solid, a well-known Ship theory's demonstration shows that float's buoyancy simply corresponds to the sum of water's elementary pressures on its immersed faces.

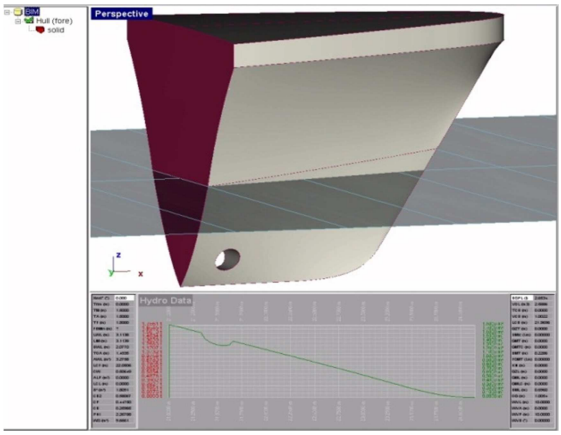



Figure 3: BREP Solid's Hydrostatic Data can be integrated directly in real-time

Finally, BREP solid's direct integration seems to be a natural and intuitive solution for integrating hydrostatic analysis more tightly into a 3D design process, allowing to analyze accurately the most complex objects as easily as the simple ones.

## 3. CLASSICAL (STATIONS BASED) / BREP SOLID BASED HYDROSTATIC COMPARISON FOR A 1 M RADIUS / HALF IMMERSED SPHERE

According to the important differences between the classical (stations based) and the direct (BREP solid based) buoyancy calculations, let us first compare the speed and accuracy of these proceedings for a 1m radius / half immersed sphere:

| | Ref. | Trapezoid Rule 20 Sta. | Trapezoid Rule 200 Sta. | Direct Integration |
|---|---|---|---|---|
| V ($m^3$) | 2.09439 | 2.08916 (0.25%) | 2.0943 (0.004%) | 2.095 (0.029%) |
| VCB (m) | -0.3750 | -0.3758 (0.21%) | -0.375 (0%) | -0.375 (0%) |
| WPA ($m^2$) | 3.14159 | 3.0175 (3.95%) | 3.1404 (0.038%) | 3.1428 (0.038%) |
| BMT (m) | 0.3750 | 0.3733 (0.45%) | 0.3749 (0.027%) | 0.3754 (0.1%) |
| BML (m) | 0.3750 | 0.3611 (3.71%) | 0.3745 (0.13%) | 0.3754 (0.1%) |
| $B^2$ ($m^2$) | 1.5709 | 1.5708 (0%) | 1.5708 (0%) | 1.5704 (0.025%) |
| WSA ($m^2$) | 6.28318 | 4.8765 (22.4%) | 4.9329 (21.49%) | 6.2838 (0.01%) |
| Mean Error (no WSA) | 0% | 1.43% | 0.029% | 0.049% |
| Mean Error (with WSA) | 0% | 4.8765 | 3.09% | 0.043% |
| Calculation Time (s) | | 0.0029 | 0.0195 | 0.0012 |

*© 2013: The Royal Institution of Naval Architects*

In this benchmark, the trapezoid rule has been ideally applied to the exact stations and not to their rough polygonal approximation.

On the other hand the BREP sphere we have integrated is only a non-rational polynomial approximation, whose features may differ slightly from the theoretical sphere.

Moreover, as many solutions are available for integrating BREP solids, we have only tested our preferred algorithm in terms of speed / accuracy ratio (response times exclude SAC's calculation which is almost as long).

## 4. BREP SOLID BASED INTEGRATION PROS & CONS

Direct BREP solid integration also provides other advantages:

- Direct BREP integration allows a more intuitive and 'lifelike' process of complex models.
- Ship's design model is almost directly usable for hydrostatic calculations.
- Ship's hydrostatic analysis has almost no complexity or topological limit.
- Float's hydrostatic features no longer depend on a sectioning grid or definition referential.
- Wetted surface can be calculated very accurately.
- WPA, BMT and BML can be calculated without aberration for flat bottom hull's lowest floatations.
- Etc…

Nevertheless, two disadvantages must also be mentioned:

- As float's integration directly operates on its 3D faces, no station is available for calculating the Sectional Area Curve, so that a heavier and more complex process must be carried out for getting this important data without stations. Fortunately, the SAC calculation is only needed for ship's upright hydrostatic analysis and can be omitted in most of the other calculations.
- Ship's BREP descriptor may sometimes be extremely heavy, especially when a lot of small construction details (fillets, chamfers, thicknesses, etc…) are included in the model, slowing down the calculations significantly without improving their accuracy. As 3D modeling allows defining a lot of geometric details very easily, the less significant ones may have to be omitted in order to avoid overloading the BREP hydrostatic engine for nothing.
- In rare cases, ship's model may be unavailable as a BREP solid (old and/or traditionally designed ships) and its lines may therefore have to be converted into an equivalent BREP solid to make its hydrostatic analysis possible.

## 5. COMPARED RESULTS FOR A 10.080 M x 4.700 M x 2.180 M TRAWLER

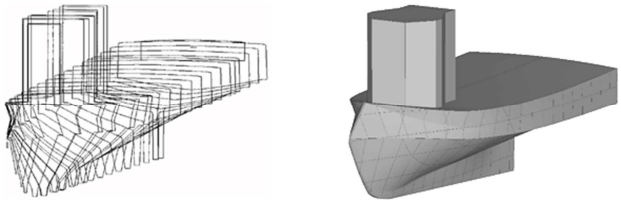


Figure 4: The compared Stations and BREP Solid models

First of all, it is important to recall that BREP integration can operate almost immediately on the design model, while the accuracy of the trapezoid rule highly depends on station's locations, which may avoid fully automating the access to hydrostatic analysis. In this example:

- Double stations must be set on SAC's potential steps (i.e. on skeg's end and cabin's front / rear faces) in order to get accurate results.
- Stations must be set on SAC's potential angles (i.e. on the 3 angles of the cabin).

The reference 'classical' results provided by ARGOS (Bureau Véritas) and the direct BREP data provided by MAAT Hydro (Sistre) are compared below:

Short Hydrostatic Data:

| DMP (m) | DSPL (t) | TPCM (t) | LCB (m) | LCF (m) | KMt (m) | KMl (m) | KB (m) |
|---|---|---|---|---|---|---|---|
| 1.40 | 16.98 | 0.34 | 4.507 | 3.835 | 3.914 | 11.89 | 1.01 |
| | 17.007 | 0.3412 | 4.5156 | 3.8399 | 3.9033 | 11.849 | 1.0085 |
| | 0.159% | 0.35% | 0.0086 | 0.0049 | 0.0007 | 0.041 | 0.0015 |
| 1.50 | 20.44 | 0.35 | 4.397 | 3.902 | 3.586 | 10.54 | 1.084 |
| | 20.468 | 0.3501 | 4.4078 | 3.9108 | 3.5901 | 10.534 | 1.0832 |
| | 0.136% | 0.03% | 0.0108 | 0.0088 | 0.0041 | 0.006 | 0.0008 |
| 1.60 | 23.99 | 0.36 | 4.331 | 3.958 | 3.324 | 9.55 | 1.152 |
| | 23.997 | 0.3552 | 4.3384 | 3.9591 | 3.3229 | 9.5211 | 1.1519 |
| | 0.029% | 1.33% | 0.0074 | 0.0011 | 0.0011 | 0.0289 | 0.0001 |

Short Stability Data:

| Heel | DMP (m) | Trim (m) | LCB (m) | TCB (m) | VCB (m) | KN (m) | GZ (m) |
|---|---|---|---|---|---|---|---|
| 0° | 1.58 | 0.047 | 4.298 | 0 | 1.142 | 0 | 0 |
| | 1.578 | 0.059 | 4.2977 | 0 | 1.1414 | 0 | 0 |
| | 0.002 | 0.012 | 0.0003 | 0 | 0.0006 | 0 | 0 |
| 20° | 1.519 | 0.004 | 4.397 | 0.615 | 1.238 | 10.54 | 1.084 |
| | 1.5182 | 0.005 | 4.4078 | 0.6139 | 1.237 | 10.534 | 1.0832 |
| | 0.0008 | 0.001 | 0.0108 | 0.0011 | 0.001 | 0.0006 | 0.0008 |
| 50° | 1.377 | 0.279 | 4.322 | 0.841 | 1.377 | 1.596 | 0.022 |
| | 1.3773 | 0.2595 | 4.3208 | 0.8387 | 1.3743 | 1.5919 | 0.0238 |
| | 0.0003 | 0.019 | 0.0012 | 0.0023 | 0.0027 | 0.0041 | 0.0018 |

*© 2013: The Royal Institution of Naval Architects*

## 5. CONCLUSION: THE VIRTUAL SHIP CONCEPT

As most of today's 3D modelers allow handling BREP solids as virtual objects, the 'Virtual Ship' concept naturally comes to mind as soon as their real-time hydrostatic analysis becomes possible.

MAAT Hydro's goal is therefore simply to **provide a Virtual Tank for simulating Virtual Ship**'s hydrostatic behavior directly in designer's 'virtual world'.

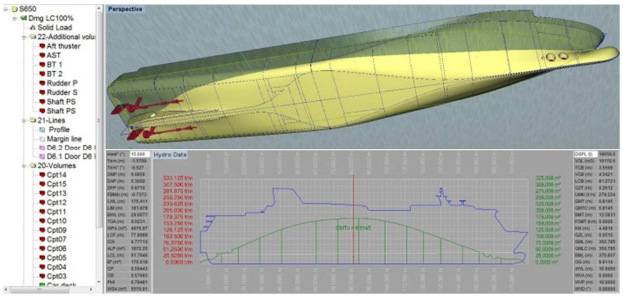


Figure 5: Virtual Ship's real-time Analysis

In order to remain intuitive, it is important to stress that, although it may be a very complex object, such a 'Virtual Ship' must remain a visual object, whose behavior must accurately replicate Real Ship's behavior, ship's solid and liquid loads having therefore to be also managed intuitively in real-time.

Combined with Designer's common sense, Virtual Ship's real-time analysis therefore allows solving instantly a lot of informal but complex hydrostatic problems and the incidence of Virtual Ship's simple or complex damages can be processed as well without any limitation:

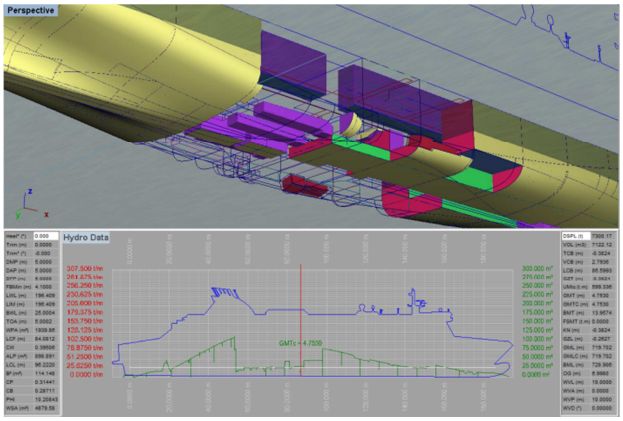


Figure 6: Virtual Damaged Ship's real-time Analysis

Moreover, for practical reasons, MAAT Hydro also provides all the reports usually requested by most of the classification societies:

- Upright hydrostatic / SAC analysis
- Hydrostatic Curves / Tanks Capacities
- Trim Tables and Curves
- Intact / Dredge stability
- Damaged stability (probabilistic / deterministic, with / without water on deck…)
- Intermediate flooding stages
- Floodable Lengths
- Cross Curves
- Max KGs
- High level Stability criterion scripting
- Etc…

## 5. ACKNOWLEDGEMENTS

The Author would like to express a special gratitude to his closest partners in the MAAT Hydro project:

- C.M.N.
- Bureau Mauric
- Verhaaren Naval Architects
- HT2
- MCHL / Mer & Design
- REDS

Moreover, the Sistre software range wouldn't be the same without the confidence of his earliest supporters:

- Jean Pierre Aubry / Gilles Gahinet
- Grégoire Dolto / Patrick Dubois (GRAAL)
- Jean Charles Nahon (Bureau Mauric)
- Dominique Presles (Presles Design)
- Robert Jean Balquet (STCAN / DCNS)
- Pierre Caloin (Forges Caloin)
- Christian Gaudin (STX)
- Rolland Joassard (OCEA)

## 6. AUTHORS BIOGRAPHY

**Marc Pommellet** actually owns the Sistre software house (www.sistre.eu), originally created in France in 1983.

Well known from the ship design CAD-CAM connoisseurs, Sistre is the pioneer company who designed the first 3D surface / desktop computer based ship design software, presented in RINA's 1984 symposium 'Computers and small Crafts' (CIRCE 3D became French Navy's hull definition standard in 1985).

Sistre also introduced the 3D surface modeling techniques in the field of ship structure generation (MAAT Structure in 1987–1993 for HP-UX workstations and MAAT 2000 in 1993–2003 for PCs) in cooperation with French shipyards and Ministry of Industry.

Tested in the CIRCE 3D environment since 1986, Sistre's direct BREP integration technique finally became the core of the MAAT Hydro project in 2003.

*© 2013: The Royal Institution of Naval Architects*