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# Sophisticated fire simulation model creation based on NAPA product model


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# 1. Introduction

Fire simulation has become a normal procedure in modern ship design process, especially when bigger passenger vessels, warships and offshore platforms are considered. Nowadays a vast variety of reliable and generally accepted tools exist for different numerical simulations, also for phenomenon as complex as fire and smoke spread. However, building up and maintaining the used simulation models with the pace of the actual design process may still appear to be the bottleneck of a risk based design from the fire safety perspective.

This paper depicts a scheme for seamlessly integrating a widely used state-of-the-art fire simulation tool into an ordinary ship design process by utilizing the existing NAPA product model as the platform for simulation integration. This scheme allows the direct use of NAPA model as the sole source for all relevant data regarding the fire simulation, including geometry, furnishing and isolation materials as well as the location of the nozzles and other parameters of the fire suppression system. Moreover, along the lines of this approach, the results of a successful fire simulation can be imported back into NAPA for a practical review, but also to be used as input in other calculations utilizing this product model, such as finite element strength analysis.

To support and ease the model generation, a NAPA Manager application based SURMA-FIRE was constructed. The manager forms a solid framework and integration point for the product model and the fire simulation. The built-in capabilities of the manager will enhance the model creation and decrease the number of potential errors made. With this manager the designer is also able to inspect the simulation model within NAPA system. Once the fire simulation is complete, the user can import the numerical simulation results back to NAPA for assessing the effects on the ship.

SURMA-FIRE will also ease the management of the numerical data as it allows linking the results and the actual ship product model.

# 2. Fire simulations with FDS

Fire Dynamic Simulator (FDS) is a software tool that applies computational fluid dynamics (CFD) on fire-driven flow. In principle the simulation is based on solving Navier-Stokes equations with numerical calculation. FDS has been developed by the NIST (National Institute of Standards and Technology) and VTT (Technical Research Centre of Finland). /McGrattan et al. 2013/.

The FDS-Smokeview package is widely used in the industry. However, since FDS is only a solver and Smokeview a mere visualization software, there is a need for sophisticated methods for building up the simulations models. In this paper the focus is on model creation and the detailed calculation features of FDS are not discussed.

## 2.1. FDS model in general

FDS model is a text-based dataset that holds all information regarding the simulated geometry and the phenomena related to the spread and development of fire. For a complex model, this file can have an exhausting number of lines, which can be difficult to manage and update. The model can be roughly divided into following sections:

- Calculation meshes, output parameters and simulation options
- Definition of the fire reactions
- Definition of the species and particles
- Definition of devices
- Definition of materials and surfaces

- Definition of geometric features

The calculation domain, i.e. the mesh, is rectilinear and all geometric features have to be described as rectangular volumes. For modelling of a ship, this generates problems that will be discussed later on. Geometric features, such as holes on obstructions, can be added. Different material properties can be imposed on the obstructions by using surface and material definitions. The species and particles introduced in the simulation have to be defined. If the simulated compartment is equipped with fire extinguishing system, locations of the nozzles and all other system characteristics have to be defined in the FDS model.

The approach introduced in this paper eases the FDS model generation in two ways: by automatically fetching data from the existing ship product model and by offering tools for managing FDS input parameters using libraries saved with the ship product model.

## 2.2. The example case

In this paper the model integration and model generation process is demonstrated using the engine room of a small offshore patrol vessel. The length of the ship is less than 40 meters and the design draught is little over two meters. The location of the example compartment is presented in Figure 1 below. Because of the small size, the vessel will be sensitive to addition of weight such as water from the extinguishing system. As the volume of the selected compartment is less than 200 $m^3$, the size of the simulation mesh could be kept moderate, which decreased the required computational time.

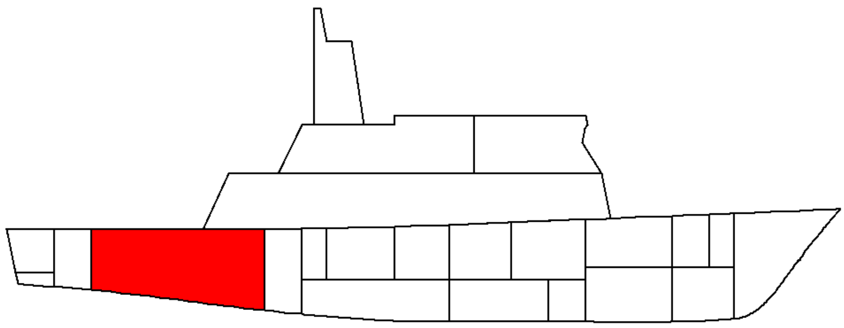


*Figure 1: Location of the example compartment*

Figure 2 below presents the FDS geometry model of the compartment which was created based on the NAPA ship product model. Transverse bulkheads are omitted from the figure in order to preserve clarity. Different materials were assigned for the side shell and the deck, illustrated with different colors. Two openings, retrieved from the structural arrangement of the vessel, were punched through the deck. The steps necessary for transferring the ship product model into functioning fire simulation model are discussed in the following chapters.

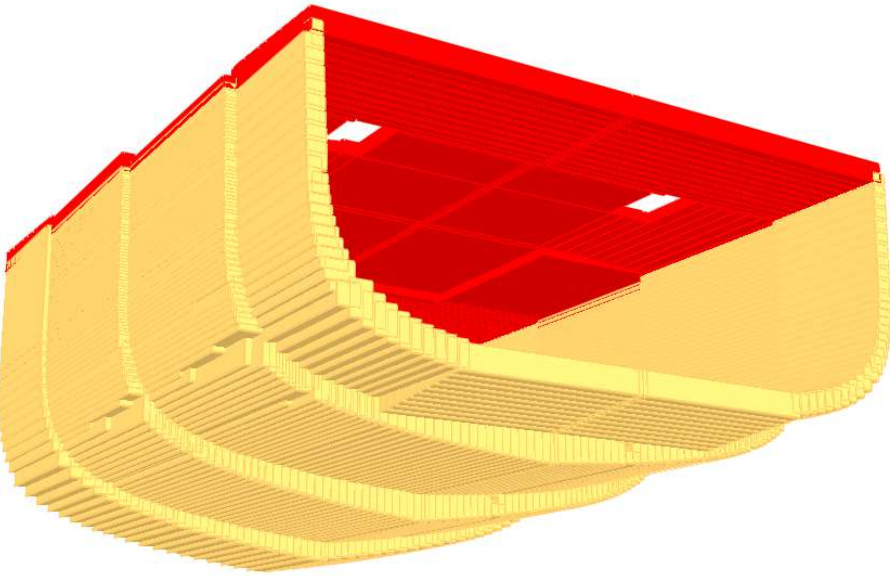


*Figure 2: FDS geometry model presenting the engine room of a small offshore patrol vessel, bulkheads are omitted from the visualization.*

# 3. From product model to fire simulation

The fundamental basis of the integration between ship's product model and fire simulation model is in vault-like thinking. As the product model database already contains information about the ship geometry, structural arrangements and equipment components, it is therefore a natural location for storing and retrieving all ship related information. In the ship design process, the product model serves as the core source when generating production information for shipyard, and statutory calculations concerning, for example, ship stability are also done using the product model.

The information included in the ship product model can be summarized as follows:

- Compartment geometry, ship general arrangement and information related to compartment, such as compartment purposes.
- Structural arrangement of the vessel, holes and openings in hull structures as well as on decks and bulkheads.
- Material properties of different structural members, both construction and insulation.
- Location and key properties of equipment on board, including fire extinguishing system and primary components, such as main engines.

By using the product model as the source for generating simulation models for other purposes, the risk of losing information and ending up having different models depicting the same ship can be minimized. In practice this will result in increased reliability of the simulations and tremendous savings in the amount of work hours as the model generation can be automated to a high level degree. The integration between NAPA and FDS, fire simulation and ship design, is presented in Figure 3 below as a flowchart. Once the numerical fire simulation results are imported back to NAPA, and linked with the product model, they are available to be used in comprehensive assessment of the response of the vessel.

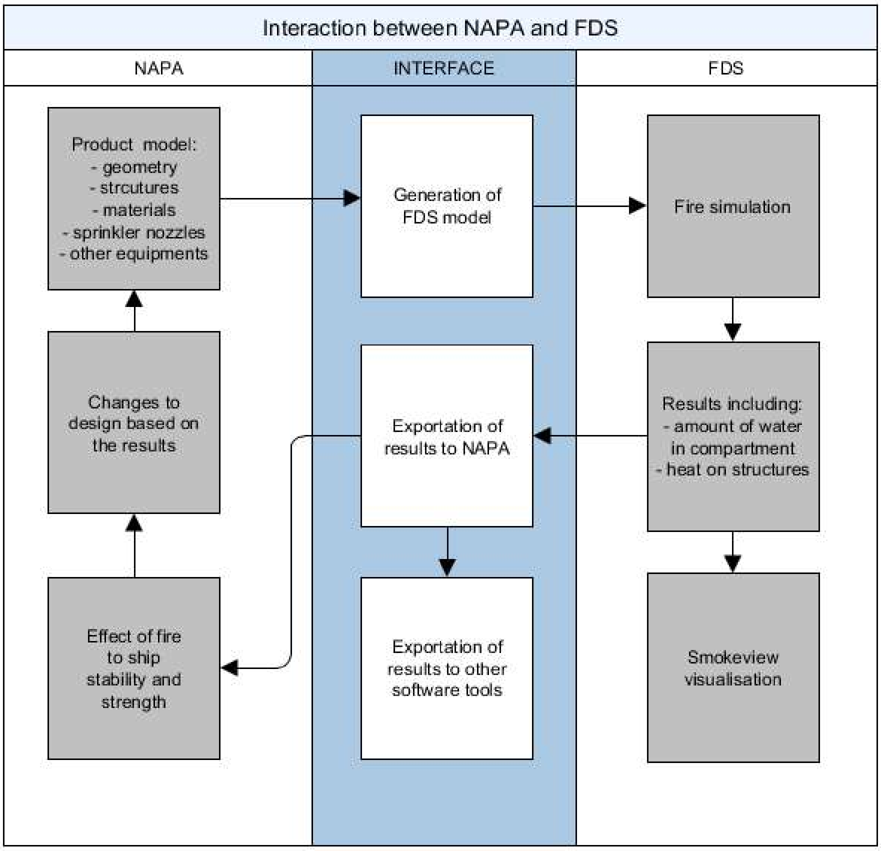
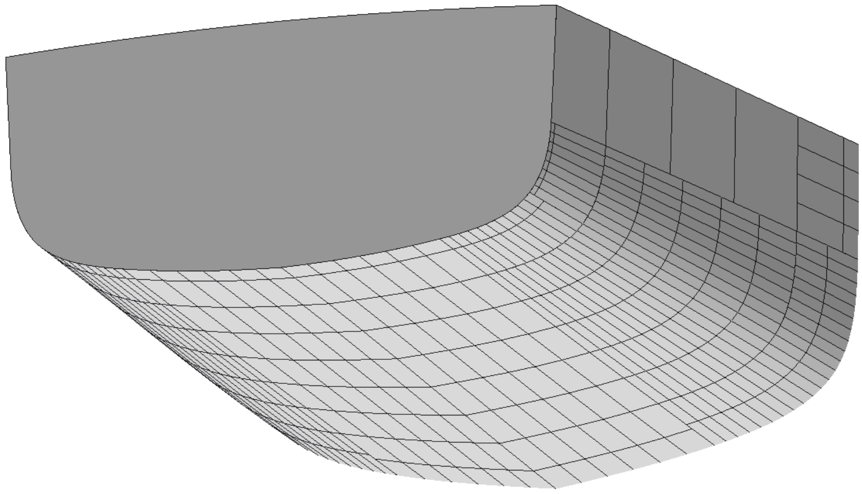



*Figure 3: Integration of fire simulation and ship product model*

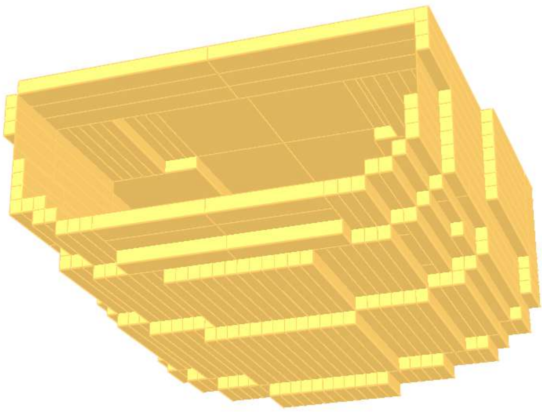
## 3.1. Transfer of geometry and material properties

Undoubtedly the biggest advantage that can be gained by the model integration is automated transfer of the model geometry including special features such as openings and material definitions. The challenge in the model generation process is the significant difference between geometry representation in the programs. NAPA uses continues surface representation, which captures well the challenging shapes of a ship, especially the curved hull surface area. In FDS the basis of geometry representation is a rectilinear mesh and all the geometric features are defined as rectangular box-shaped obstructions /McGrattan et al. 2013/.

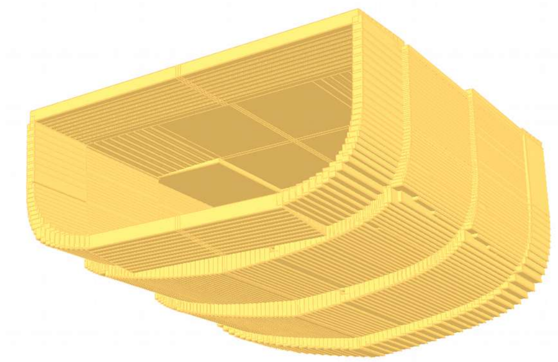
The difference between the two representations can be seen in Figure 4 below. The figure on the left side (Figure 4 A) presents the engine room as a NAPA surface and the other two (Figure 4 B, C) the FDS representation. To enable the fetching of geometric data from the product model, an advanced method for processing the NAPA geometry was developed.



A) NAPA surface



B) FDS surface, coarse mesh



C) FDS surface, fine mesh

*Figure 4: Comparison of NAPA and FDS surface representations*

In order to successfully present a NAPA-origin geometry in FDS, all shapes that are either curved, or are not parallel to the coordinate axes, have to be modified. This was done using 3D-rectilinear modelling grid approach. The method transforms non-planar and non-orthogonal shapes to discretized surface representation and replaces all surfaces with rectilinear modelling grid. This grid can then be interpreted as the basis for FDS obstruction definition. Transformation of the geometry is fast, effective and automatic, removing the modelling phase that was the former bottleneck of the process.

Although the above presented example compartment has a relatively simple geometry apart from the curved hull surface, ship's compartments usually have a number of reductions and additions that make them irregularly-shaped. With the described geometry transfer, all these parts can be included in the fire simulation model just the way they are in the actual ship product model as is presented in Figure 5 below. If required, geometric details, such as holes and openings, can be retrieved directly from NAPA Steel, the structural module of NAPA. Provided that the material parameters have been defined in NAPA Steel, these parameters can be included in the generated FDS obstruction definition. If these definitions have not bee made, the designer may assign materials for desired sections of the compartment by using the developed tools.

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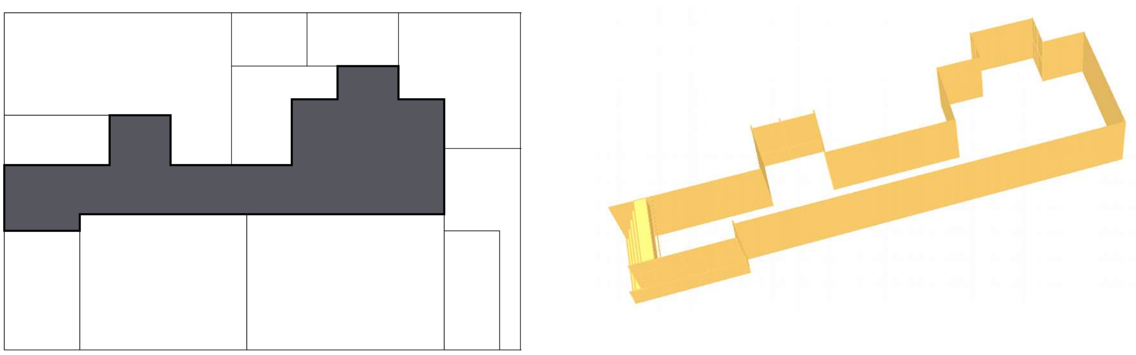

A) General arrangement presenting the compartment, viewed from above

B) FDS model of the compartment, only walls showed

*Figure 5: Transferring irregularly-shaped geometry from NAPA to FDS*

It should be noted that the mesh cell size division has to be chosen in accordance with the dimensions of the obstructions. If the obstructions are too thin, they are ignored /McGrattan et al. 2013/. The cell division should be chosen based on the dimensions of the model and characteristics of the fire /McGrattan et al. 2013/ and then checked by visually inspecting the generated model.

## 3.2. Sprinkler nozzles, thermometers and other devices and equipment

Different types of equipment, which are part of the actual ship, have location on board and have equipment specific properties can be modelled in NAPA using a module called NAPA Outfit. Usually only large components having weight and space implications on the ship, such as main engines, big pump units and HVAC machinery are modelled with NAPA Outfit. However, the flexibility of the Outfit module enables its usage also for other purposes, like modelling of sprinkler nozzles, thermometers and similar equipment components, relevant from the fire simulation perspective.

The locations of thermometers and other measuring points can be easily defined in NAPA. The definitions can be done simply in ship coordinate system and, if desired, an algorithm that places the measuring points at certain distances with respect to the geometry, can be used.

In addition to the locations of the equipment, also the essential equipment and system parameters can be saved in NAPA as an equipment library. Having the data saved and linked with the product model also supports the vault-like thinking, easing the management of different types of equipment on board. This feature can also be used for making sure that the equipment properties, such as sprinkler system flow rate and system setpoint, are the same for all similar components. If the equipment parameters have to be changed, the alterations are automatically applied to all components of the same type ensuring that the simulations models are up-to-date.

# 4. Effects of fire on ship

As mentioned in the beginning, fire and fire fighting bring a handful of contradicting challenges to the naval architects table. Even though effective sprinkler systems are today more or less a part of the standard outfitting of almost every vessel, their extensive use has the potential of endangering the stability of the ship. This is the case especially with small vessels but also with respect to larger ships having big continuous full-width decks and relatively small initial metacentric height, such as RO-RO vessels and passenger cruise vessels.

On the other hand, prolonged fire associated with intensive heat release increases the internal temperatures in ship's structures and yields in degrading strength of construction materials. Depending on the location and the actual materials used, this 'softening' may lead to loss of structural integrity, i.e. to collapse of decks and bulkheads, but can also compromise the ship's longitudinal strength.

Since the successful assessment of both of these hazards evidently requires naval architectural calculations to be performed, it seems a natural step to try and get the fire simulation results back into ship design environment. In the following two examples, the simulation results from two different fire scenarios have been imported back into NAPA system and processed there to yield appropriate data, which is then utilized as input for normal damage stability and longitudinal strength analysis.

## 4.1. Water on deck

To observe the effect of water released by a typical fire extinguishing system with sea water sprinklers, the engine room fire was simulated for 246 seconds with six sprinklers having the flow rate of 180 litres per minute and activation temperature of 74 °C.

In Figure 6 these results can be seen as three curves, one showing the accumulated amount of water from sprinklers and the other two indicating temperature histories outside the structures and in inner wall structure respectively from selected measuring points.

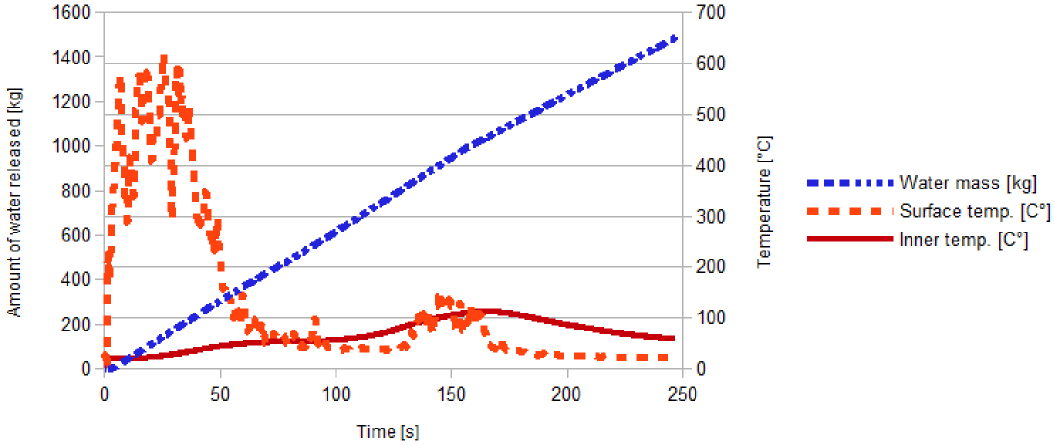


*Figure 6: Histories of accumulated water and temperatures outside and inside structures.*

The total amount of accumulated water in this simulation was quite moderate, yielding only 1484 litres. When the fire simulation terminated, this data was read into NAPA system from an ordinary CSV. file, and formatted to comprise a normal damage stability calculation case. Also this data exchange between the programs was automated by writing it in a NAPA macro.

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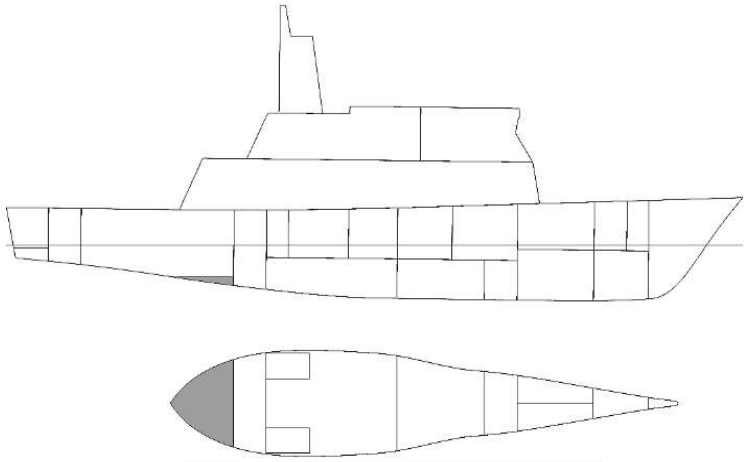
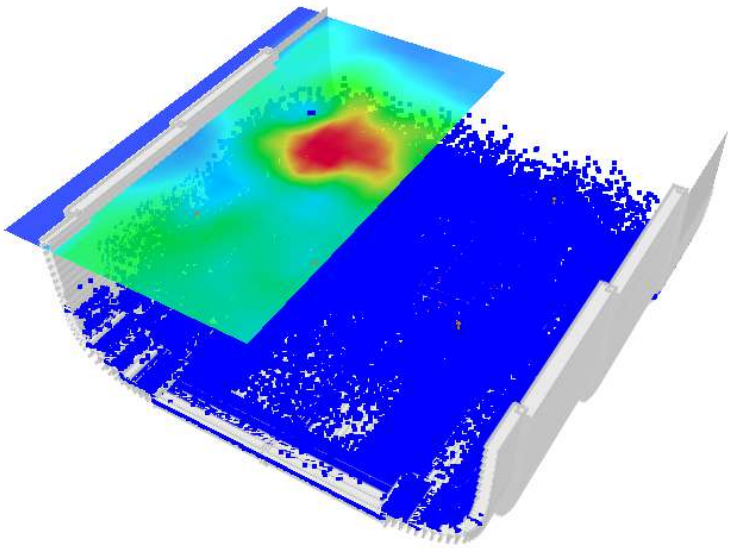
Even if the amount of water from this simulation doesn't threaten the ship stability wise, the changed state can be seen in damage stability calculations. A floating position plot and listed results from NAPA are shown in Figure 7 A) and simulated action of sprinklers in FDS in Figure 7 B).



| CASE | STAGE | FLW t | T m | TR m | GMACT m |
|---|---|---|---|---|---|
| FULL/KOE2 | INTACT | 0.0 | 2.743 | 0.438 | 1.010 |
| FULL/KOE2 | 1 | 1.5 | 2.749 | 0.423 | 0.989 |

A) NAPA floating position diagram



B) Smokeview visualization of the compartment, active fire extinguishing

*Figure 7: Sprinkled water in the ship.*

## 4.2. Heat on structures

To observe the effect of increased temperature on structures, another scenario of the engine room fire was simulated for 370 seconds with no sprinklers acting and the temperatures outside as well as inside the structures were measured in several points, forming seven 'zones' in vertical direction.

In Figure 8 these results can be seen as curves, those with label starting with 'C NW' showing the temperatures within the compartment yet outside the structures and those with label starting with 'C IW' indicating temperature histories from point inside the actual structures.

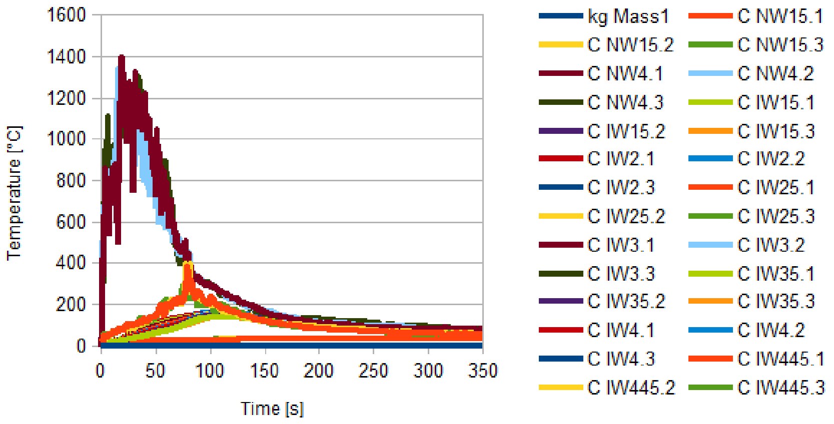
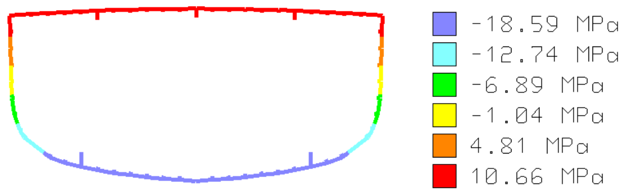


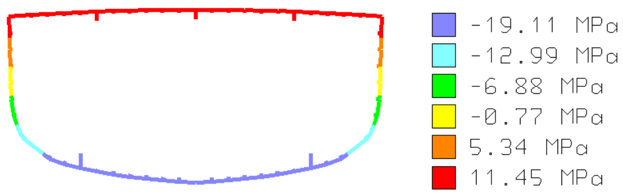

*Figure 8: Temperature histories outside and inside structures with no sprinklers acting.*

As can be seen from Figure 8 also the temperatures inside the structures increased well above 200 °C and stayed there for a period of tens of seconds. When the simulation terminated, the temperature histories were read into NAPA, and the averages of the maximum inner temperatures for the seven zones at different heights were calculated. For the assessment of this effect on longitudinal strength, a SECPRO model was generated in NAPA. This 2D FEM module enables the calculation of different properties of a cross section based on the NAPA Steel structural model, and yields the stresses acting in it.

To estimate the thermal effect on structural strength, a curve describing material behaviour of steel with respect to increased temperature was adopted from Eurocode 3 /The European Union 2005/. The 'softening' of steel was then taken into account by a factor calculated for each zone from this curve and applying it as decreased plate thickness on the SECPRO model as no better way to realize this was found at the time of writing this paper. The results of the SECPRO analysis are visualized in Figure 9.




A) Initial state




B) Fire affected structures

*Figure 9: Longitudinal strength assessment*

# 5. SURMA-FIRE – The manager application

To support and ease the fire simulation model generation, a NAPA Manager application SURMA-FIRE was constructed. The manager forms a solid framework and integration point for the product model and the fire simulation model. The built-in capabilities of the manager enhance the model creation and decrease the number of errors made by allowing the designer to review and inspect the model within NAPA and by helping the management of defined FDS variables. Once the fire simulation is complete, the user can import the numerical simulation results back to NAPA for assessing the effects on the ship.

The functionalities of the manager can be roughly divided into two sections, namely modelling and result management. Process tree in Figure 10 below presents the structure of the manager. The different functionalities of the model are presented and discussed in the following chapters. The model generation is started by defining materials, surfaces and other relevant FDS parameters. NAPA geometry is transformed into format suitable for FDS and all other relevant information, such as openings, equipment and devices are added. Defined materials are linked with the geometry.

In the second section the manager offers tools for the designer to import the results back to NAPA and for managing the imported results. The effects of fire and fire extinguishing to the ship's stability and strength can be reviewed. Results are presented for each simulated compartment or case in separate folders.

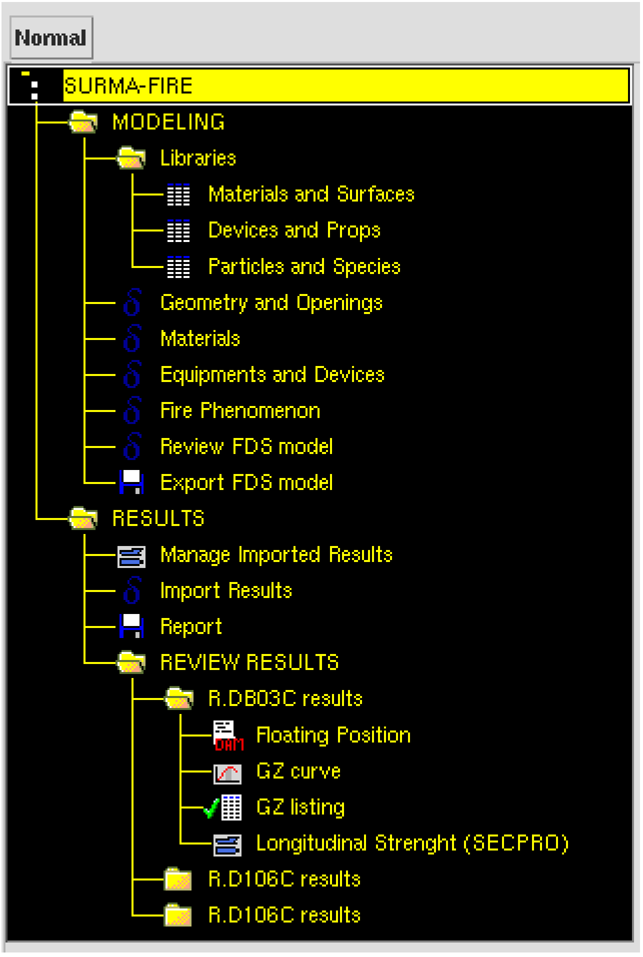



*Figure 10: Manager process tree*

SURMA-FIRE manager also supports the presented vault-like thinking in which all information is stored into one database and fetched from there for different uses.

**Model building and data handling**

Modelling data can be divided into compartment data and simulation data. Compartment data is related to the specific compartment, such as geometry definitions and different equipment, for example locations of sprinkler nozzles. Simulation data is more general and holds definitions of, for example, different gas species and material and surfaces properties. In general, simulation data contains information that is common to the whole ship. The herein presented manager application offers tools for handling both data types. Simulation data, i.e. the common data, is collected into library tables and the designer does not need to define these for every compartment separately. This also reduces the number of mistakes made in the modelling process. Also the manager does not allow the use of, for example, gas species that have not been defined.

The SURMA-FIRE manager automatically fetches data from NAPA database, for example opening definitions are fetched straight from NAPA Steel. Material definitions can also be fetched from the product model, but the manager offers a graphical tool as an alternative for assigning the surface properties.

The majority of the information is stored in NAPA as tables, which allows the use of NAPA's flexible and efficient table handling capabilities. Equipment definitions, such as sprinkler nozzles, are modelled using NAPA's Outift module via the SURMA-FIRE manager.

**Visual inspection and model review**

As was stated earlier, FDS uses rectilinear geometry representation instead of continuous surfaces. As this is significantly different from NAPA's continuous surface representation, a functionality for inspecting the compartment geometry as rectilinear representation within NAPA is required. Figure 11 below presents an OpenGL illustration of ship's compartment as rectilinear geometry representation in SURMA-FIRE manager application. Each FDS obstruction is plotted with different colour. If an error is encountered, the designer can use NAPA's functionalities provided in the manager to examine the error. If required, also equipment components and devices can be visually reviewed.

It should be noted that the selected mesh size has an effect on the FDS/Smokeview geometry representation and this impact is not considered in the manager's visualization functionality.

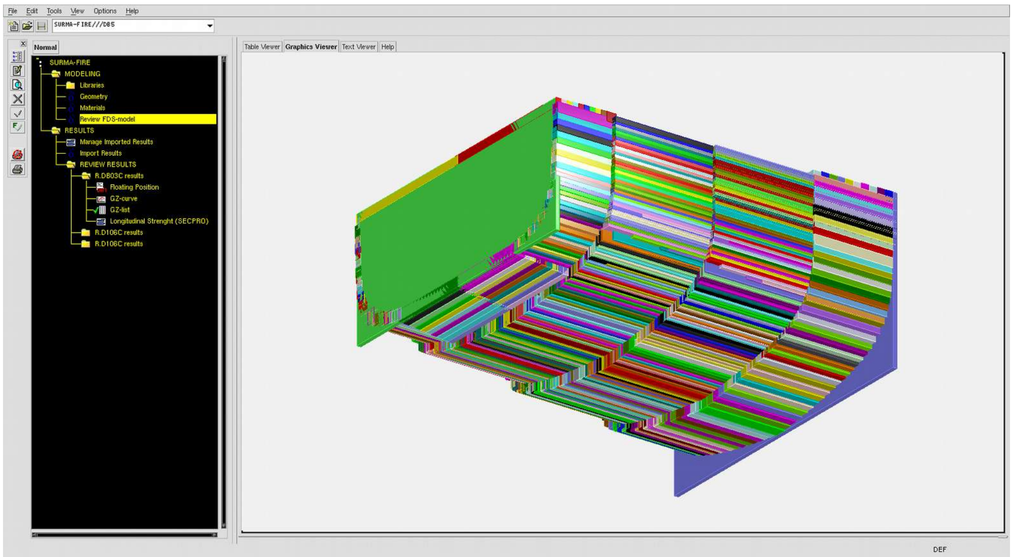



*Figure 11: Model geometry review in manager*

The user can also view the text-based FDS model in the manager application and add and remove text before exporting the model for the actual fire simulations. This allows the user to add header texts or comments to the FDS model, or make quick changes for testing purposes.

## 5.1. Managing, reviewing and reporting results

In order to fully integrate the ship product model and fire simulation model, the results can be imported back to NAPA for calculating the effect of fire and fire extinguishing on the ship's floating positions and longitudinal strength. SURMA-FIRE manager also enables management of the imported results and allows the designer to combine simulation results of different compartments in order to, for example, estimate the impact of active multi-compartment fire extinguishing system on ship's stability.

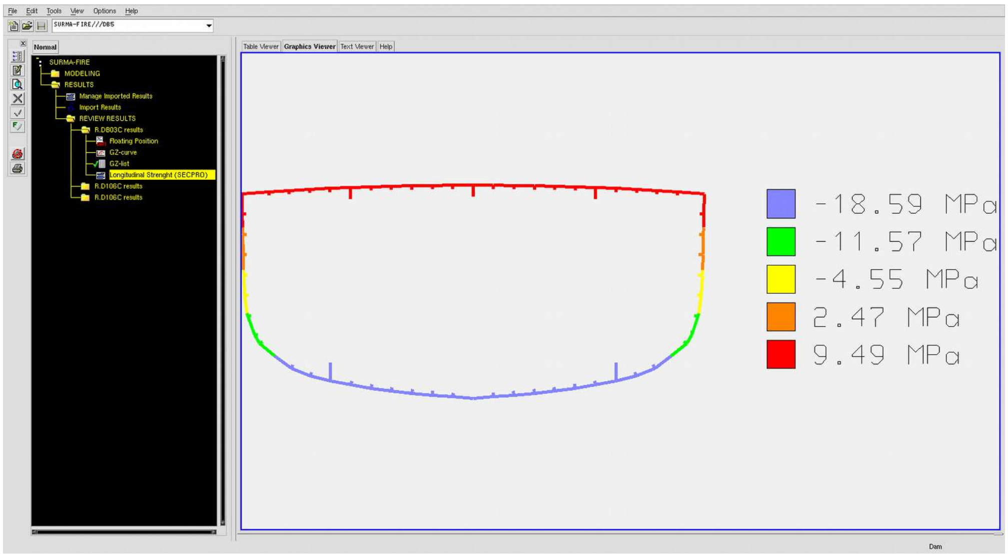
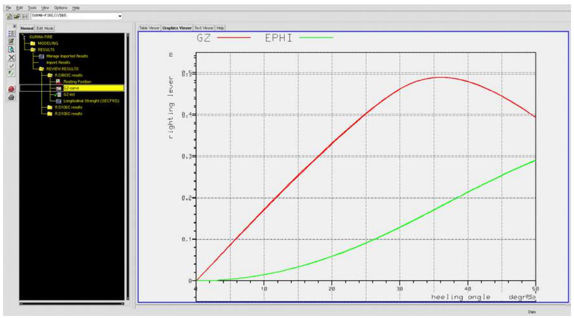


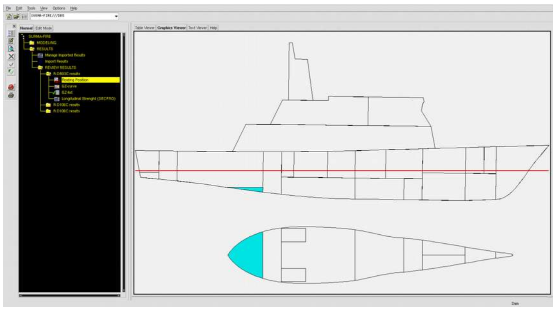

*Figure 12: Longitudinal strength analysis are done using SECPRO, results viewed in manager*

The longitudinal strength analysis is performed using NAPA's SECPRO service functions and stability is assessed using standard damage stability calculation module. Figure 12 above presents and example of the cross section stress distribution plot. Currently the material softening model in strength calculations is based on EUROCODE 3, but other methods can be implemented as well.

Especially when small ships or ships with large full-width decks are considered, the impact of fire extinguishing water in a compartment may effect on the ship's floating position or even compromise the stability of the vessel. For this reason, the statical stability curves (GZ curves) and the ship's floating position after fire event can be reviewed in the SURMA-FIRE manager application. An example of this is presented in Figure 13 below.




Statical stability curve (GZ)



Floating position

*Figure 13: Stability assessment presenting the statical stability curve (GZ) and floating position, results viewed in manager*

SURMA-FIRE manager offers reporting tools utilizing NAPA's DocBook implementation. Figure 14 presents a preview of a fire simulation report. Depending on the users preferences, the report can contain information about the fire simulation models, for example what materials were used, what the fire phenomenon was and what were the measured temperatures. Stability and strength figures and listings can also be exported in different file formats.

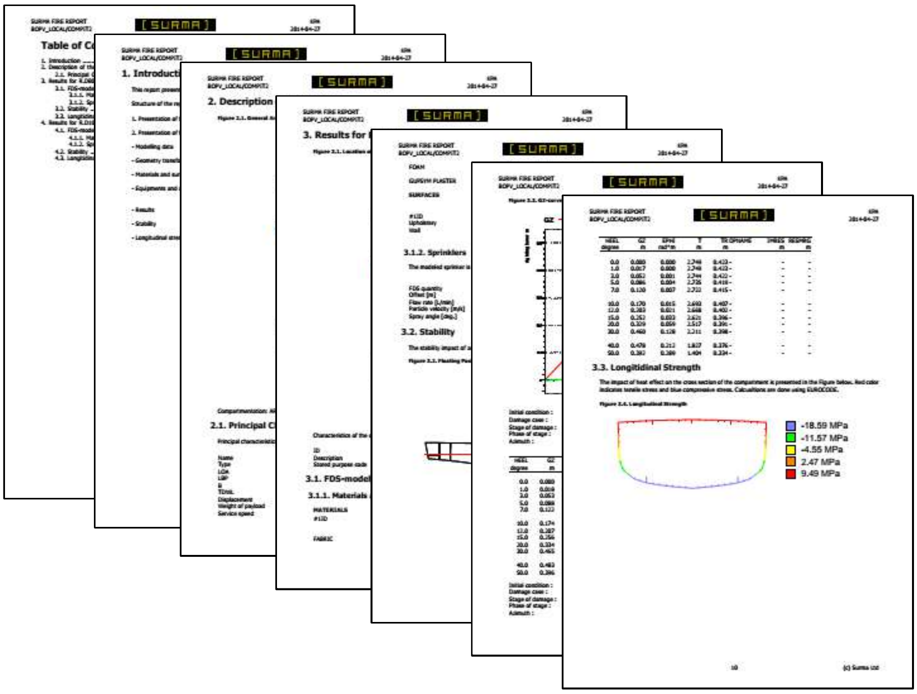


*Figure 14: An example of the report generated with the manager*

# 6. Further considerations

As is always the case with new approaches, many details of the herein presented method need some tinkering and tailoring, and often the place for adjustment is only found with case studies in practice. Never the less, this chapter presents some ideas that have come up during the writing of this paper, which would make this approach even more usable in the future.

There is room for improvement and fine tuning in the algorithms of the 3D-rectilinear modelling grid generation, especially when exceptional compartment geometries are concerned.

Fire simulations are often incorporated with evacuation simulation and also for FDS an evacuation module EVAC is available. A natural step for further work would be to extend the presented integration procedure to comprise also evacuation aspects.

The vault-like thinking introduced in this paper could be extended by improving the possibilities to transfer data between different design and simulation environments. For example, this could mean tools for transferring system and equipment data from dedicated design tools to NAPA environment. This would benefit fire simulation model creating as the equipment data is likely to concern the fire aspects as well.

The analysis of the effects of fire and fire extinguishing on the ship could be extended towards more comprehensive ship survivability assessment supporting the analysis of safe return to port requirements. The assessment could answer questions such as what are the functionalities lost due to fire and what is the operational capability of the vessel.

The functionalities of the presented manager application, SURMA-FIRE, could be extended and further improved. For example, more visual inspection capabilities could be added and, for example, a feature for graphically assigning locations for measurement devices could be added. More flexibility could be added on the reporting routine. If the presented product model integration is extended to cover also evacuation simulations, the manager needs to be also updated.

# 7. Conclusions

This paper has introduced a method for integrating the fire simulation to the ship design process. The approach is based on idea that the fire simulation model is already existing within the ship product model and there is no need to re-create and re-model anything, only to transfer data between simulation and modelling environments. The presented method allows fetching of geometry and material properties as well as data of fire extinguishing system from the product model and facilitates solutions for fire simulation data management within the ship product model. Numerical simulation results can be imported back to NAPA ship design environment for assessing the ship's response in terms of stability and structural integrity. The developed method supports mastering the simulation data of different compartments centralized within the ship product model, thus enabling the incorporation of multiple simulations into the ship's overall response assessment.

The presented manager application is an efficient tool for transforming the ship's NAPA product model into FDS fire simulation model. The manager is also the core integration point between these programs allowing exporting and importing results between the programs.

# 8. References

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