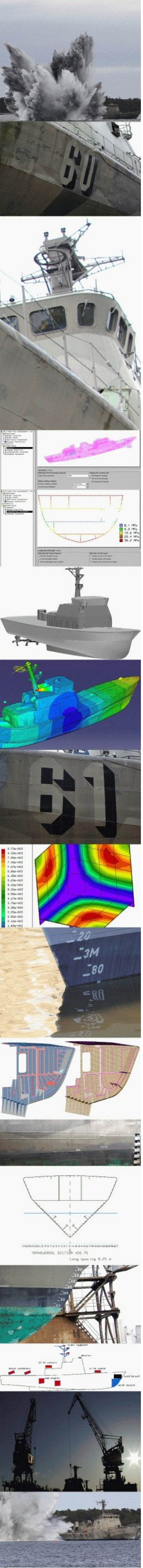

SAFE RETURN TO PORT
[SURMA]

SURMA Technical Description SURMA-M-101-G
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SURMA Technical Description

Software for Comprehensive Navy Combat Survivability Analysis

Survivability Manager Application SURMA is a software tool for comprehensive navy combat survivability assessment. The goal is to enhance the combat survivability features from the very beginning of the design process. The first SURMA release is intended for the design of naval vessels, taking account the effects of UNDEX and AIREX either inside or outside the vessel.

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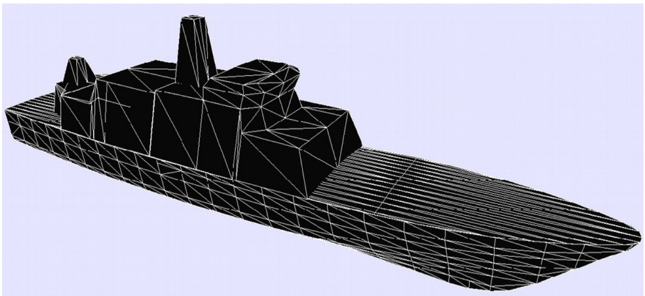
1. SURMA Analysis Features

On a general level, the capabilities of SURMA can be divided into three categories according to the main aspects of the classical definition of survivability, hence susceptibility, vulnerability and recoverability. Preceding the actual SURMA analysis the user can set up a threat scenario, which can consist of several different weapons with different hit location probabilities. These probabilities can be automatically generated based either on simple principles like percentage of outer surface per room or according to more sophisticated means like analysis results from radar cross section calculation.

1.1. Susceptibility – How to stay out of the trouble

Currently the susceptibility part includes two types of signatures considered important, namely the underwater magnetic signatures and the radar cross section calculation. The former is implemented as a built-in feature and the latter as an interface to an RCS calculation tool CAST.



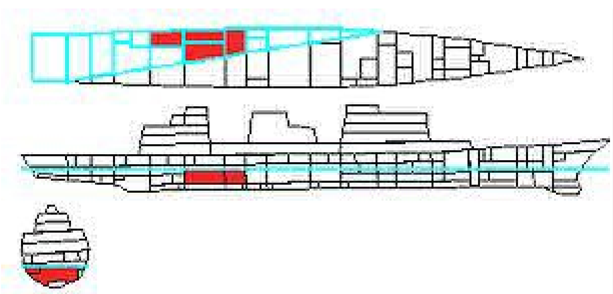
Calculation of the underwater electromagnetic signature is performed with a simplified dipole model, which derives the ferromagnetic properties of the structures from NAPA Steel model and magnetic data given for the equipment components from SURMA system definition.

For RCS analysis SURMA currently provides only a one-way link for outputting the geometry of the vessel's outer surfaces as a triangulated surface representation in a file format accepted by an RCS calculation software CAST, which is developed and owned by the VTT Technical Research Center of Finland and used by the Finnish Navy.

1.2. Vulnerability – How to reduce the trouble

The vulnerability part of SURMA is basically divided into two different aspects, AIREX, explosions of conventional warheads in air and UNDEX, underwater explosions.

AIREX analysis first generates the pressure histories resulting from a warhead detonation and acting on the structures based on semi-empirical formulas. If the detonation occurs in a confined space inside the vessel also the quasi-static pressure build-up is calculated. This calculation takes into account the type and mass of the explosive filling of the warhead, but also the energy required to fragment the warhead casing. The semi-empirical formulas used in SURMA are selected based on their best correlation with performed testing and more complex numerical simulations. An arbitrary number of warheads with different parameters can be defined. In case the user has better knowledge of the performance of the warheads, this data can be incorporated into SURMA assessment for example in terms of excel spread sheets or m-files without the need to disclose this information. The dynamic structural response is then calculated based on a single degree of freedom system, constructed for every naturally formed structural element. The SDOF analysis includes non-linear structural behavior such as the membrane forces and material models associated with high strain rates. The collapse of structural elements is estimated based on equivalent plastic strain which is calculated for every loaded element during the analysis.



Currently SURMA considers only primary fragments resulting from the warhead fragmentation. Mott-Gurney equations are applied for calculating the mass distribution of the fragments and their initial velocity. Thor-equations are used for assessing perforation and the residual velocity of the penetrating fragments. Also air drag is taken into account when analyzing the fragment propagation. SURMA can also use predefined data like fragment mass, geometry and initial velocity, if the user has this kind of information. The properties of different types of ballistic protection can be modified in terms of coefficient for the Thor-equations, thus taken into account when calculating the range of penetration for the fragments.

Current implementation of the UNDEX analysis consists of four aspects:

1. Local response of hull plating to shock loading and possible hull rupture.
2. Global response of ship hull girder to shock loading.
3. Global response of ship hull girder to gas bubble pulsation (whipping).
4. Local shock response aboard the ship (deck levels and equipment).

The local shock response of hull plating is based on similar SDOF analysis that is used also for the AIREX analysis. The shock wave loading at ship hull is described using an exponentially decaying pressure wave. Reflection at ship hull, local cavitation and surface cut-off are taken into account.

For the global shock and whipping response a simplified hull girder beam model is utilized, which basically treats the hull girder as a slender beam having different cross sections with varying geometric parameters and lumped masses at beam element nodes. These cross sections and the masses are derived from the NAPA Steel model. The added mass of the surrounding water is calculated from the hull geometry applying the 2D Lewis forms and a correction factor for taking into account the 3D flow effects. The shock and whipping responses are obtained by transient analysis.

The global shock loads affecting the beam model are obtained by equating the response of ship cross section at each node to an equivalent water column with equal draft. The response of water column during shock wave loading is calculated incrementally up until to the time of surface cut-off. After surface cut-off the ship cross-section is decelerated by atmospheric pressure and gravity. This approach leads to a unique load history for each node, taking into account different load magnitudes, durations and shock wave arrival times to these nodes.

The gas bubble pulsation is described using a model that assumes the fluid to be incompressible and irrotational. Compressible phase of the explosion is neglected and the bubble is assumed to remain spherical. Migration of the bubble and free surface effects are taken into account. The gas bubble energy loss during consecutive oscillations is accounted for via a semi-empirical correction factor.

For the local shock response aboard the ship several sub-models are used. Vertical attenuation of shock is modeled using an MDOF spring-mass system. The shock response of equipment is analyzed by a beam-mass model, where the deck is represented as a beam and the equipment as a spring-mass model. The equipment attachment can be modeled as rigid, linear or nonlinear shock isolator. This kind of sub-model correctly takes spectrum dip effect into account. Finally, a pseudo-velocity shock response spectrum is automatically created for each bulkhead-deck intersection and each equipment.

It's noteworthy that user can also create and output a finite element mesh from SURMA to be used in an external FE software like Abaqus.

The vulnerability assessment in both cases, AIREX or UNDEX follows the same path –

1. First the structural response is calculated. If the structural damage includes holing in the shell plating, a damaged stability analysis is performed applying the damage stability module of NAPA.

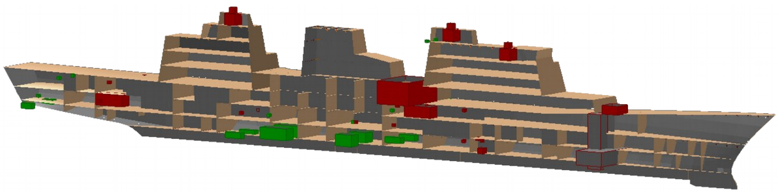
2. If the vessel's damaged stability and floating position remain reasonable, the longitudinal strength is calculated taking into account the damaged structures and the change in the loading condition due to the possible flooding.
3. If the residual longitudinal strength is appropriate, the functionality of modeled equipment components is checked. The equipment components can currently have up to 7 different kill criteria, namely water pressure, air pressure, heat intensity, temperature, acceleration, shock response spectrum and impulse absorbed from kinetic energy. All components are checked against relevant criteria during a SURMA run and once the killed components are flagged, the system functionality analysis is conducted considering also redundant components and routes.

Based on the assessment a report defining the design's mission readiness level in given threat is generated.

1.3. Recoverability – How to get out of the trouble

Beside the instant effects from weapon effects, also certain aspects of recoverability can be assessed within SURMA. The possible progressive flooding can be analyzed with built-in NAPA tools yielding elapsed time before any critical events occur.

SURMA equipment definition also enables the user to give limits in terms of above mentioned kill criteria indicating if the equipment components or routes are repairable after certain incident. This facilitates a recoverability analysis showing what parts of system functionality can still be restored.



SURMA also includes two recoverability related interfaces. The other one is an interface to a widely used fire analysis code called Fire Dynamics Simulator, FDS. The other is a link to a software system named Integrated Recoverability Model, IRM. Both of these interfaces are currently implemented only on proof on concept level, hence without more excessive testing.

2. Modeling Environment

SURMA application is built on top of NAPA system and beside the SURMA specific analysis, the features and calculation tools offered by NAPA are used extensively. SURMA functionality is implemented as a combination of external executable which uses NAPA via application programming interface NAPA API and a few NAPA macros and table definitions enabling the use of a customized NAPA manager application as the graphical user interface for SURMA.

As SURMA uses extensively the features offered by NAPA model, there are some requirements regarding this model.

The fundamental feature required from the NAPA model is the compartment arrangement containing the room definitions of the vessel. The compartment arrangement amended with default structural properties can be used for basic SURMA assessments in terms of AIREX. Compartment arrangement also provides the basis for damage stability calculations and the outer surfaces of the vessel for signature assessment purposes, such as radar cross section calculation.

If a NAPA Steel model is available, SURMA derives the structural parameters and material properties from it. This enhances the resolution and accuracy of the dynamic structural analysis in SURMA remarkably. NAPA Steel model is also essential for SURMA UNDEX analysis. Therefore the users are encouraged to utilize this module of NAPA system.

A module called NAPA Outfit is used in SURMA for building up the systems. NAPA's outfit concept consists of equipment definitions and route definitions. Both of these are basically normal table definitions where the parameters for equipment components and connecting routes are given. Parameters associated with equipment components include type, location, dimensions or shape, mass and several other parameters. Routes are defined as line segments representing different connections between equipment components, i.e. piping, wiring, etc. Beside their location, parameters such as type and cross section can also be assigned to routes.

Within SURMA the equipment components and the routes are assigned different kill criteria to facilitate functionality analysis. Furthermore in SURMA the equipment components and routes are collected to a master hierarchy called system definition. This addition enables SURMA to assess the functionality of vital systems having redundancies and dependencies on other systems.

2.1. Product Model Detail Level

For SURMA analysis purposes the best data to receive from the user would be a NAPA database of the ship model to be used in the survivability analysis. If needed the delivered data from design office to analysis organization can be limited.

The more information there will be in the NAPA db the more accurate and thorough the analysis will also be. For example if the NAPA model contains any system component descriptions those can taken into account, if the model database includes the structures the right scantling data is used in the analysis. The minimum requirement for the first SURMA analysis in each project is to have the main geometry and the compartmentation defined.

The need for input information depends on the purpose of the analysis and the stage of ship design process. Here are some principals on this -

1. Initial combat survivability analysis
    - GA
    - hull geometry
    - warhead information and threat scenario
2. For more accurate analysis
    - main structures
    - main system with their components
    - equipment kill criteria
3. For most detailed analysis we need
    - all scantling information
    - all system components and routes
    - detailed threat scenario

3. SURMA method compared to traditional analysis

Currently most of the assessments related to navy combat survivability in general require a lot of labor when each of the different phenomena are analyzed using separate computer codes and models. These processes lead to three main obstacles that inhibit the information from being useful in modern ship design process -

1. The results from these analyzes come usually in months rather than days. This time is too long for a normal iterative ship design process.
2. The analysis can be performed at very late stages of the design process, thus any large modification is usually very expensive to make or even impossible.
3. Due to the complexity of the phenomena the interpretation of the results requires an expert of each field and the designers cannot really benefit or learn that much from the assessment data.

To avoid these traditional problems in integrating combat survivability analysis into design process SURMA utilizes one model concept and simplified physics based calculation in all the analysis integrating the analysis to the design process allowing also the analysis of novel designs and materials.

3.1. Uncertainties and accuracy

The assessment of a naval vessel's survivability involves numerous uncertainties, which are basically related to the complex nature of the interaction between the weapon and the ship. These include for example the probabilities of the weapon hitting the target and detonating in certain location, but also the statistical features as well in the weapons effects as in the ship's response.

To ensure conservative results despite the uncertainties SURMA employs a philosophy where the most obvious variable, namely the hit location is associated with a probability and the events occurring after the hit are calculated deterministically. SURMA uses also worst case approach in cases where analysis of all the possible events of the actual phenomenon would require infinite number of simulations. One such example is fragment damage.

It is also noteworthy that even if the assessed vessel is well enough known to enable accurately detailed model definition, the mentioned uncertainties, related with weapon and its interaction, introduce a remarkable uncertainty to the assessment. The resulting inaccuracies related to these uncertainties are usually of such an order of magnitude, that they don't justify 'scientific' calculations, such as CFD or FEA, to be used in the analysis of consequent effects and resulting damage.

Shortly, SURMA analysis is accurate enough to serve the design process and SURMA calculation is more accurate than the threat scenario definition used as the input value for the combat survivability assessments.

3.2. Integration to Design Process

To enable a successful and beneficial integration of combat survivability assessment into design process it is necessary to eliminate the problems of the traditional methods. In other words it is mandatory to reduce the turn-around time of the analyzes and also receive the results in such a form that a designer working on the ship project can effectively use to improve the design. Both of these goals can be achieved by tuning the working methods.

The calendar time consumed for analyzes is reduced enormously by automatizing the model creation for the analysis software. With other solutions a noticeable amount of the working time in analysis process is taken by the building and maintaining the computer models. Depending on the survivability aspect or phenomena at hand, this can take up to half of the working hours per assessment.

Another method to get the assessment results faster to the designers is to simplify the assessments calculation. In many cases, the analysis software tools have been created to support a scientific approach and the research of the phenomena. This approach is good in cases when exact results are needed. However, the requirements from ship designers' perspective are more or less different. Quite often just an indication of whether a solution is better than another is enough, and usually the exact level of signatures seen from all the directions is not needed. This means that if the results are accurate enough with a faster analysis code, it serves the designers' needs.

To make sure the designers can improve their design after getting the results, the analysis report must be short and easy to comprehend. If the designer can get just a few values – for example, the maximum level of a signature or the level of a signature seen from a specified sector – then it is much easier for them to aim at lowering these values and improving the design signature-wise.

4. Interfaces to further analysis

- FE analysis (Nastran, Abaqus...)
- Radar signature (VTT CAST)
- Fire simulation (NIST FDS)
- Recoverability simulator (TNE IRM)

5. Requirements

- Windows PC (32/64 bit), 2 Gb, 60 GB.

6. Validation

Selected validation tests:

- Helsinki-Class tests 2008-2012 (FIN-GER-US)
- Scaled test series 2010-2011 (FNRI)