eSAFE

enhanced Stability After a Flooding Event

A joint industry project on Damage Stability for Cruise Ships

Project Summary

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What is eSAFE

- eSAFE is a Joint Industry Project initiated by the CSSF
  - CSSF: Cruise Ship Safety Forum – a tripartite organization of cruise operators, class societies and ship builders to enhance safety of cruise ships
- A group of CSSF members has sponsored the work.
  - Carnival, RCCL, DNVGL, LR, RINA, STX France, Fincantieri, Meyer Werft
- The work has partly been carried out also by external parties
  - MSRC, University of Trieste, NAPA, NTUA, Brookes Bell, Meyer Turku
- Duration of the project: 18 months (2017-2018)

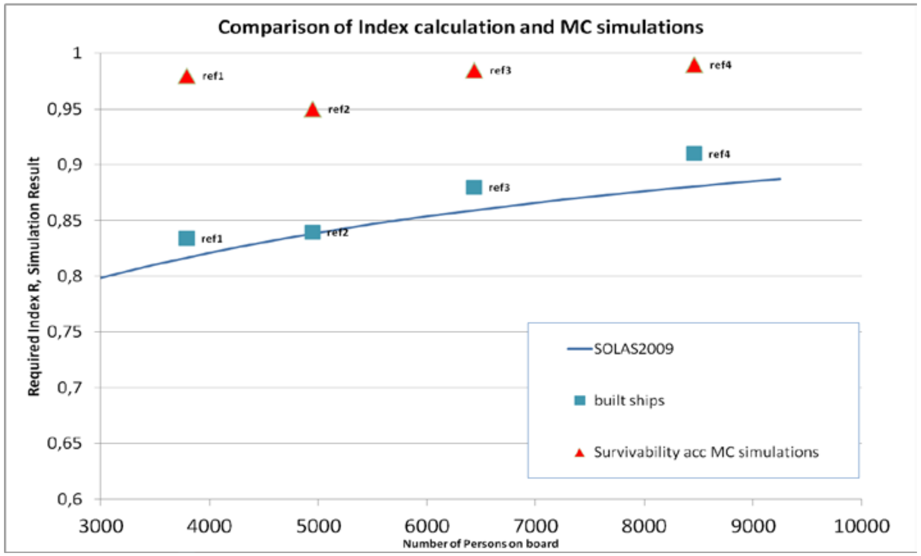
Motivation to establish eSAFE

eSAFE

- Safety level as indicated by SOLAS is significantly different to real case experiences and numerical simulations
- e.g. Costa Concordia stayed afloat for many hours, even though she was built to SOLAS90 standard
- Survivability indicated by simulations is >95%
- Damage Stability Regulations are largely based on model tests on RoPax
- Huge difference between RoPax and cruise ships
  - Different hazards and accident frequencies
  - Different sinking behavior (rapid capsize vs slow sinking) due to different internal subdivision

→ Need to have a closer look into damage stability for cruise ships

→ Explain the gap between SOLAS and numerical simulations



- What can we learn from real operational patterns of cruise ships?
- Do we find a way to combine collision and bottom grounding and side grounding/contact into one methodology?
- How should an s-factor look like, which is based on cruise ships rather than ropax?
- We need a common industry standard on how to model internal subdivision of cruise ships for static and dynamic calculations
- Numerical simulation tools need to be validated by CFD and guidance has to be developed for acceptance of such simulations by approval bodies
- A systematic comparison of sample ships is needed to understand the different results for static calculations and time-domain dynamic simulations

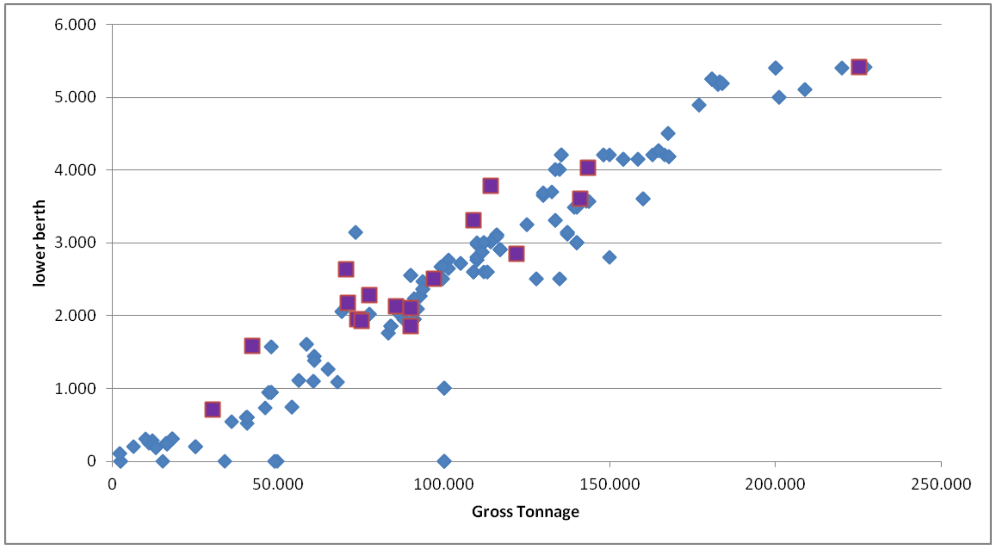
We need to be able to assess the real safety level with regard to flooding of cruise ships and based on this, set appropriate standards

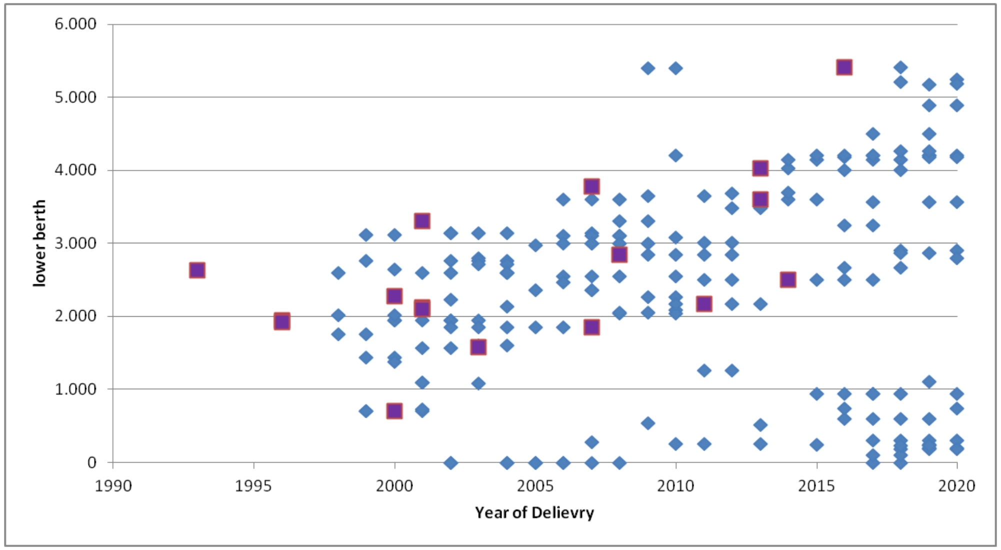
Structure of damage stability assessments

SOLAS approach	
SOLAS permeabilities SOLAS draughts	Basic input data
SOLAS probabilities (damages of lesser extent) SOLAS damage zones („zonal approach“)	definition of hull breach
Stages and phases A-class boundaries	sequence of flooding
SOLAS S-factor	survivability
Attained subdivision index A	Survivability Index

Collection of onboard data

- Size and number of persons cover wide range of the fleet
- Very small cruise ships are missing
- 17 ships of different size and age
- 393 loading conditions





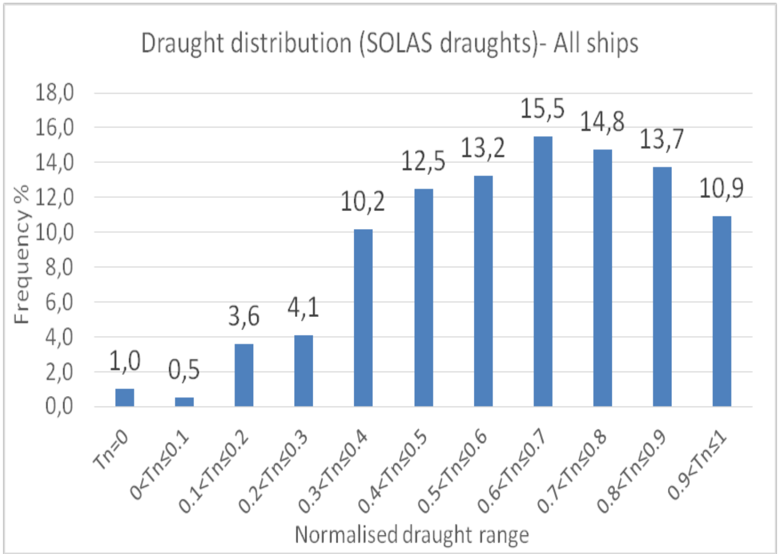
Findings from Onbard Survey

Initial draughts:

SOLAS 3 draught approach not suitable

Two approaches recommended:

- **1-draught approach** considering only the subdivision draught to be used **for numerical simulations**
- **2-draught approach** based on non-dimensional draughts 0.15 and 0.65 and weighted at 0.1 and 0.9 respectively **for static calculations**



Permeabilities

Variable permeability for tanks recommended

→ See paper Mike Cardinale et.al.

Basic structure of the project

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- SOLAS requirements focus on collision accidents
- Damage statistics show a significant risk also from bottom grounding and side grounding and contact
- Bottom grounding only covered by regulation II-1/9
  - Minimum double bottom height
  - Rather small extent of bottom damage to be survived if no double bottom is available
- Side grounding is not addressed at all

→ See paper Gabriele Bulian et.al.

Combined methodology

The total societal risk due to flooding is given by the contribution from different types of accidents:

Total **RISK** = Risk due to **collision** + Risk due to **bottom grounding** + Risk due to **side grounding / contact**

The review of the available risk models for collision and grounding indicate that they are not consistent enough to be used in a combined methodology.

Further research is needed, but in the meantime:

- A robust and validated tool to calculate collision, bottom and side grounding is available
- Attained indices for collision, bottom grounding and side grounding/contact are to be considered separately

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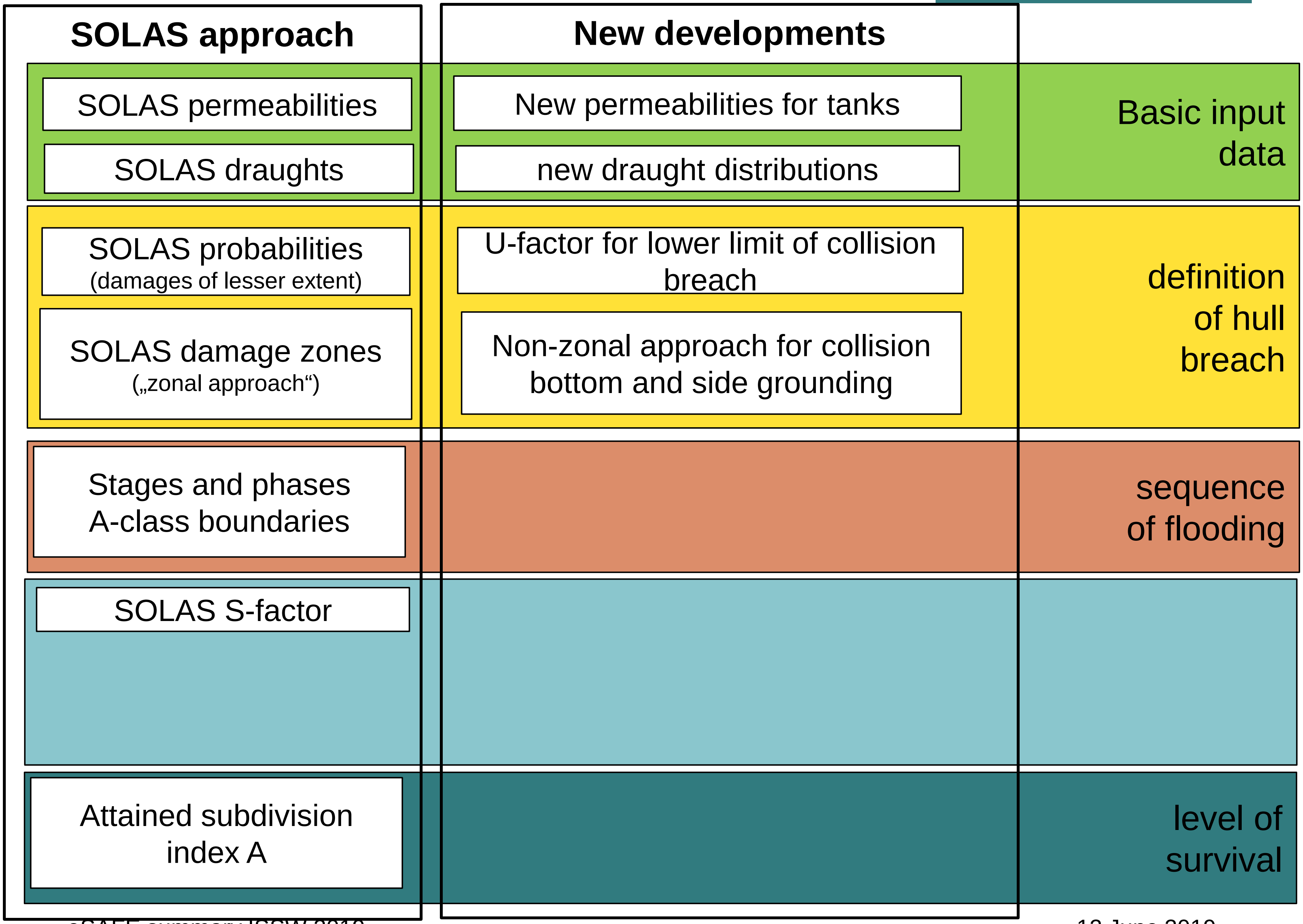
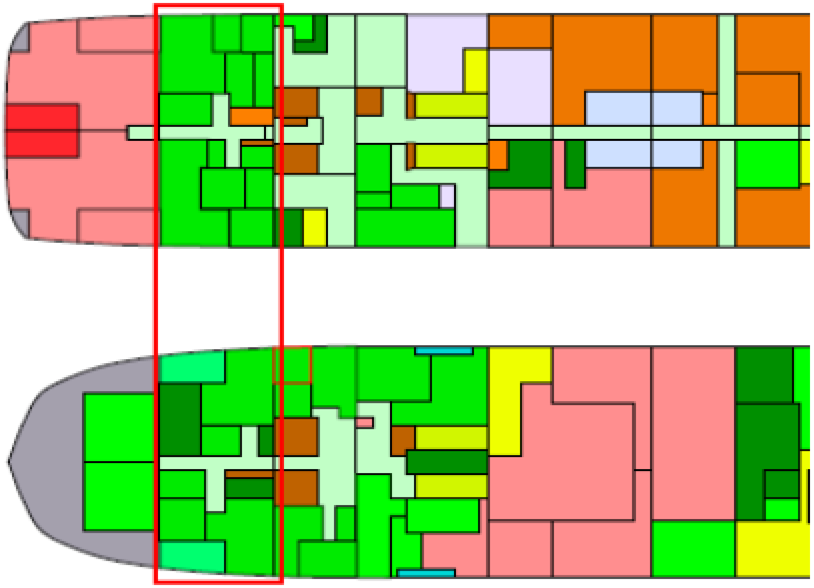


Internal non-watertight boundaries

Internal non-watertight subdivision of cruise ships may be very complex.
All possible combinations would lead to too high number of stages

e.g. one zone damage → >100,000 stages

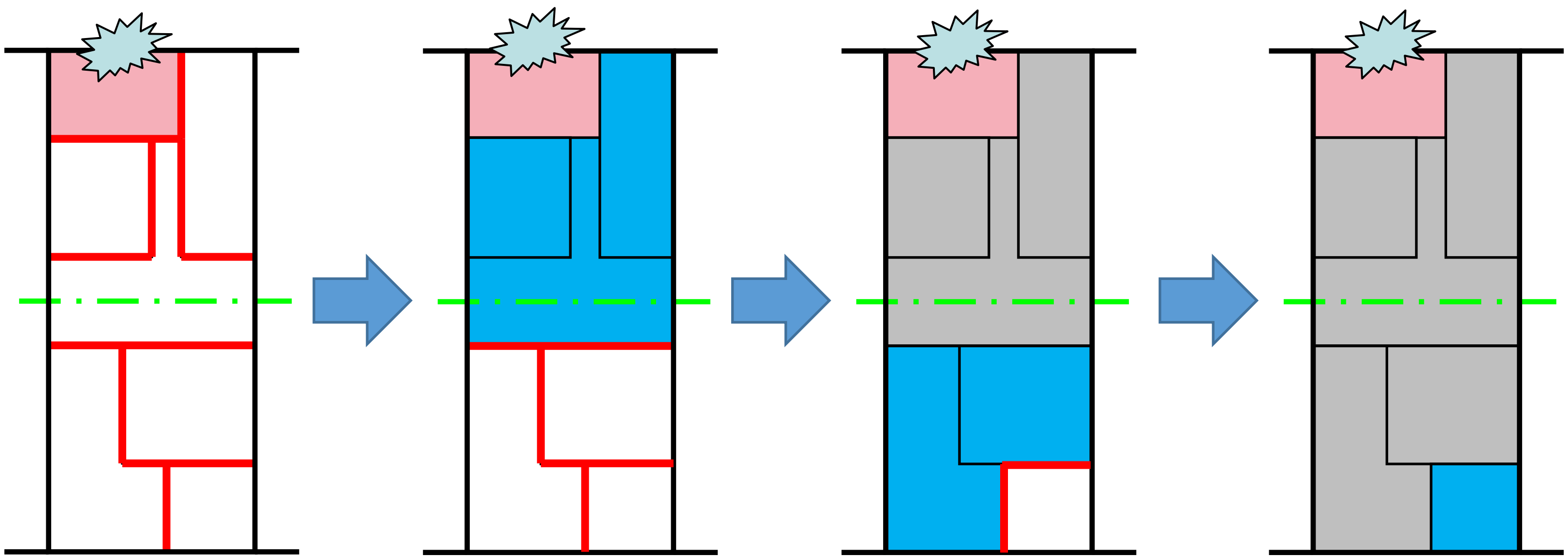


New practicable approach:

WT boundary

A-class

Principle of **"neighbouring"** spaces used for the definition of intermediate stages



In each subsequent stage, spaces neighbouring those already flooded and separated by A-class boundaries, are set open to the sea

→ New approach shows the same or slightly conservative results compared with previous approaches

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Stages and phases A-class boundaries	Agreed handling of A-class boundaries	sequence of flooding
SOLAS S-factor		survivability
Attained subdivision index A		level of survival

Validation of numerical simulations

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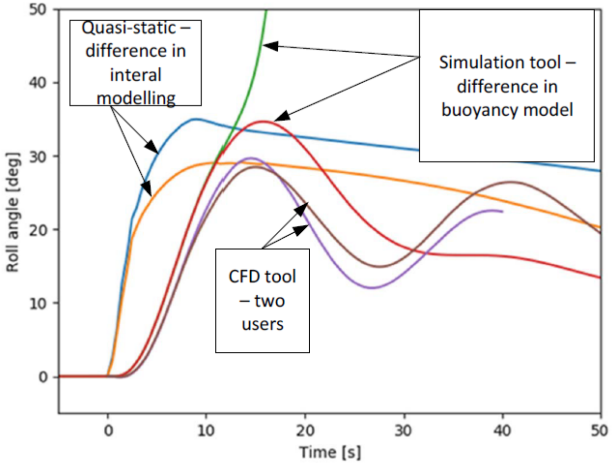
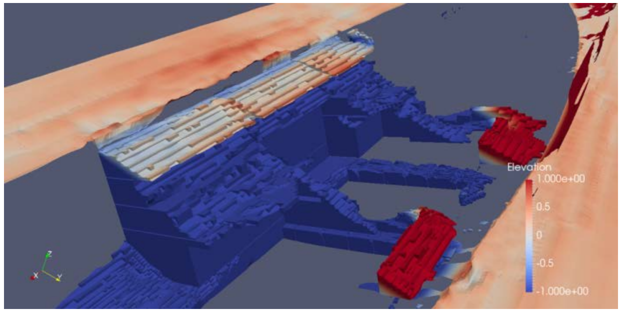
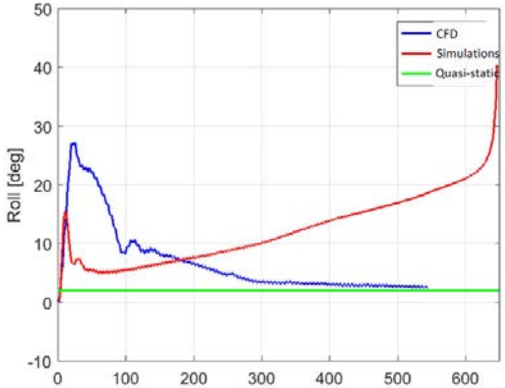
- Numerical simulation tool validated with CFD
  - Reasonable correlation for transient flooding in calm water and waves
  - Larger differences for progressive flooding in regular waves
    - Causes not obvious
- Guidelines developed for third party review of numerical tools
  - Transient flooding
  - Assessment of critical wave height
- Simulation results are very sensitive on modeling assumptions
  - Guidelines for modeling developed
- The different tools have their strengths and weaknesses
  - Calculation time
  - calm water vs waves
  - Ship dynamic response
  - investigation of details vs overall survivability

→ See paper Eivind Ruth et al.







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SOLAS S-factor		survivability
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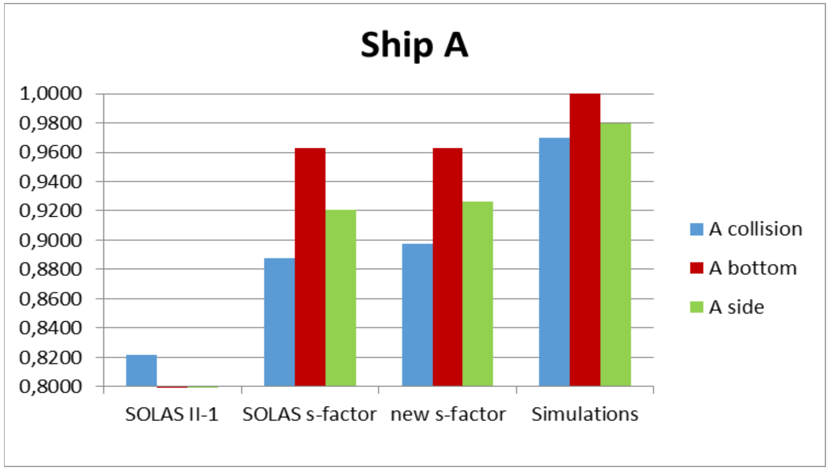
Floatability assessment

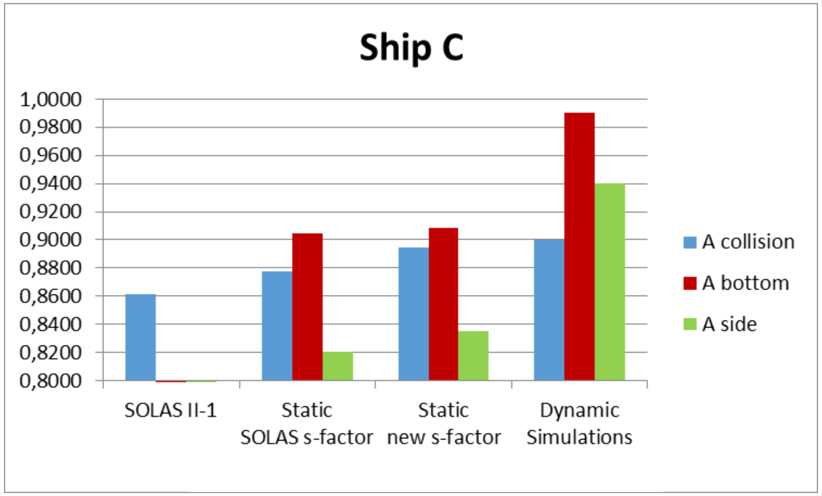
- SOLAS s-factor includes parameters that are not directly related to the survivability of the ship
  - Maximum heel <7(15) degrees
  - Immersion of escape routes and emergency stations
- Additional floatability index defined
  - Aspects related to evacuation or LSA deployment disregarded
  - New floatability index$_F$ to be seen in addition to SOLAS attained index
  - No k-factor (impact of heel on s-factor)
  - Capsize criterion (<20 degrees including external moments)
- The floatability index is better comparable with simulation results

- A new s-factor has been developed in a two step approach
  - Sensitivity study with regard to operational areas and different wave heights
  - Development of new s-factor for cruise ships based on simulation results

Comparison of static results and simulations

- Overall results of simulations show better survivability, but the same tendencies as for static calculations can be found
- Both ships behave differently in particular with regard to grounding
- Very interesting knowledge gained
  - The same weak areas of design have been found as in static calculations
  - The assumptions for static calculation may lead to very conservative results
  - The reason for failure in a specific case differ from static calculations, calm water simulations and simulations in wave
- Simulations have been proven to be a practical and better tool to estimate the safety after flooding events than SOLAS
- The gap between simulation results and static calculations has been significantly decreased
- **→ See paper G.Atzampos et al.**





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Stages and phases A-class boundaries	Agreed handling of A-class boundaries Numerical time-domain simulation CFD simulation	sequence of flooding
SOLAS S-factor	Floatability assessment New s-factor for cruise ships s-factor for operational areas	survivability
Attained subdivision index A	Numerical time-domain simulation	level of survival

Conclusion 1(2)

- Significant steps forward in understanding of flooding events
- Differences between SOLAS attained index and results from simulation cannot be completely explained
- We have now alternatives for floatability assessments with different focus:
  - Conservative A index calculation according to SOLAS as the basis
  - Non-zonal approach for collision, bottom and side grounding/contact
  - CFD simulations to get better understanding of individual damage cases and problems like transient flooding
  - Numerical time-domain simulations for assessing critical wave heights
  - Numerical time-domain simulations for overall assessment of survivability
- Common understanding about reliability and purpose of different methods and assumptions based on CFD validations
- CFD calculations give better knowledge about transient flooding and for specific situations where flows are complex

Conclusion 2(2)

- Combined risk-based approach for collision and grounding is not suitable at the moment due to high uncertainty of data in the underlying risk model and the possible adverse consequences on new designs
- Experience to be gained and shared in the future to understand the impact of design changes on the attained indices for collision, bottom grounding and side grounding/contact
- Comparison of simulations and static calculations show a higher safety level in the simulations. The gap between both approaches has been significantly reduced and simulation have been established as a suitable tool to investigate designs
- Knowledge and tools have been developed to enable provision of safety beyond SOLAS compliance
  - Robust method for collision and grounding
  - New s-factor made for cruise ships of different size
  - New approach for an overall floatability assessment supported by onboard data
  - First steps made to establish alternative methods to assess survivability after flooding

Next steps:

- Findings of eSAFE have been transferred into voluntary recommendations for CSSF members

- New EU funded research project started
  - **Fl**ooding **A**ccident **Re**sponse
  - Duration June 2019 – May 2022

More information:

- eSAFE Executive Summary: https://cssf.cruising.org/projects/
- Proceedings of the 13th International Conference on the Stability of Ships and Ocean Vehicles, 16-21 September 2018, Kobe, Japan
- Project management
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