Review of regulatory framework of

Damage Stability of Dry Cargo and Passenger Ships

Two main categories of regulatory concepts and methodologies for the assessment of ship's damage stability are nowadays in use, namely the deterministic and the probabilistic ones, leading to corresponding regulatory survivability standards (criteria).

- **Deterministic approaches** to ship's damage stability are based on **prescriptive, semi-empirical rules and criteria derived from statistical analysis of historical damage data and practical experience**. Because of the semi-empirical way of deriving the applied criteria, these methods cannot ensure a reliable minimum level of required survivability in case of new ship designs deviating from the past, nor is the attained level of ship safety known.

- The **probabilistic approach** to damage stability relies on a **rational statistical assessment of historical accidental data** and combines this statistical information with semi-empirical criteria to more **rationally assess ship's survivability by use of a probabilistic concept that takes into account a vast amount of possible damage scenarios with proper weight**.

Assessment methods of damaged stability of ships

- Deterministic Approach
  - Semi-empirical, prescriptive requirements, e.g. SOLAS74, SOLAS 90
  - Performance-based (experimental or numerical simulation approaches), e.g. SOLAS 95 – Stockholm Agreement
- Probabilistic Approach
  - A.265, equivalent to SOLAS74
  - Risk-based, …SOLAS 2009
  - Goal-based, …new SOLAS 2016+…

Deterministic vs. Probabilistic Approach to Ship Stability

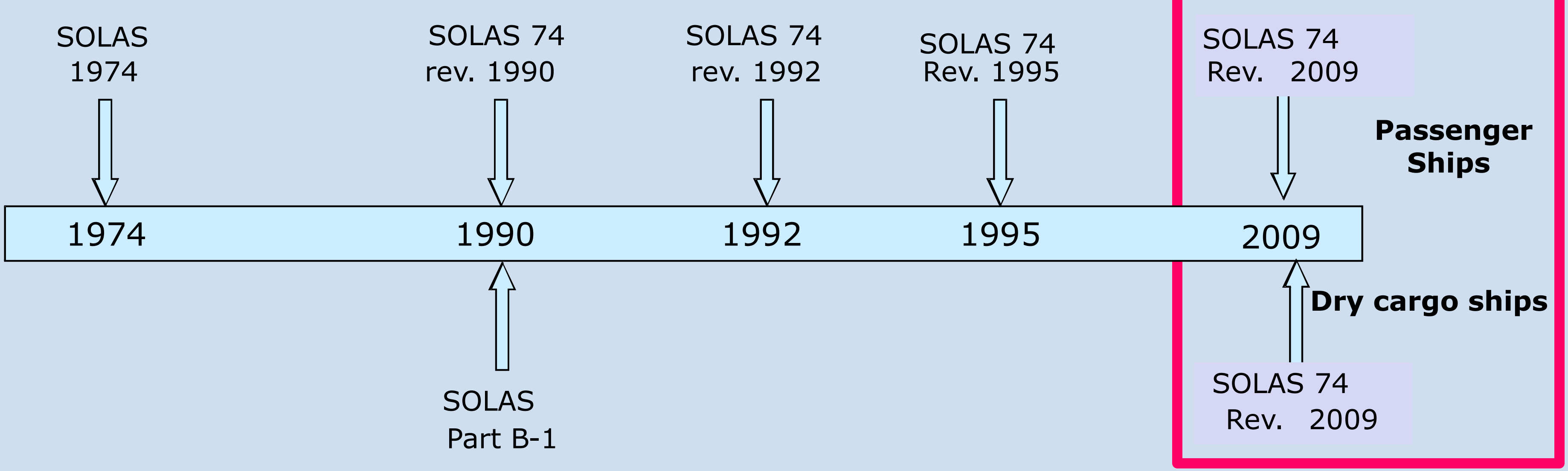
The probabilistic assessment allows the determination of ship's specific survivability (safety) level against capsize in case of flooding due to collision damages through her Attained Subdivision Index (probability of survival collision damages), whereas a deterministic damage stability standard does not correspond to a quantifiable safety level.

Recent revisions of SOLAS damage stability regulations (last 40 years)

The regulatory requirements on ship's damage stability differ depeding on ship type:

- Passenger ships (SOLAS)
- Dry cargo ships (SOLAS)
- Liquid cargo ships (MARPOL)

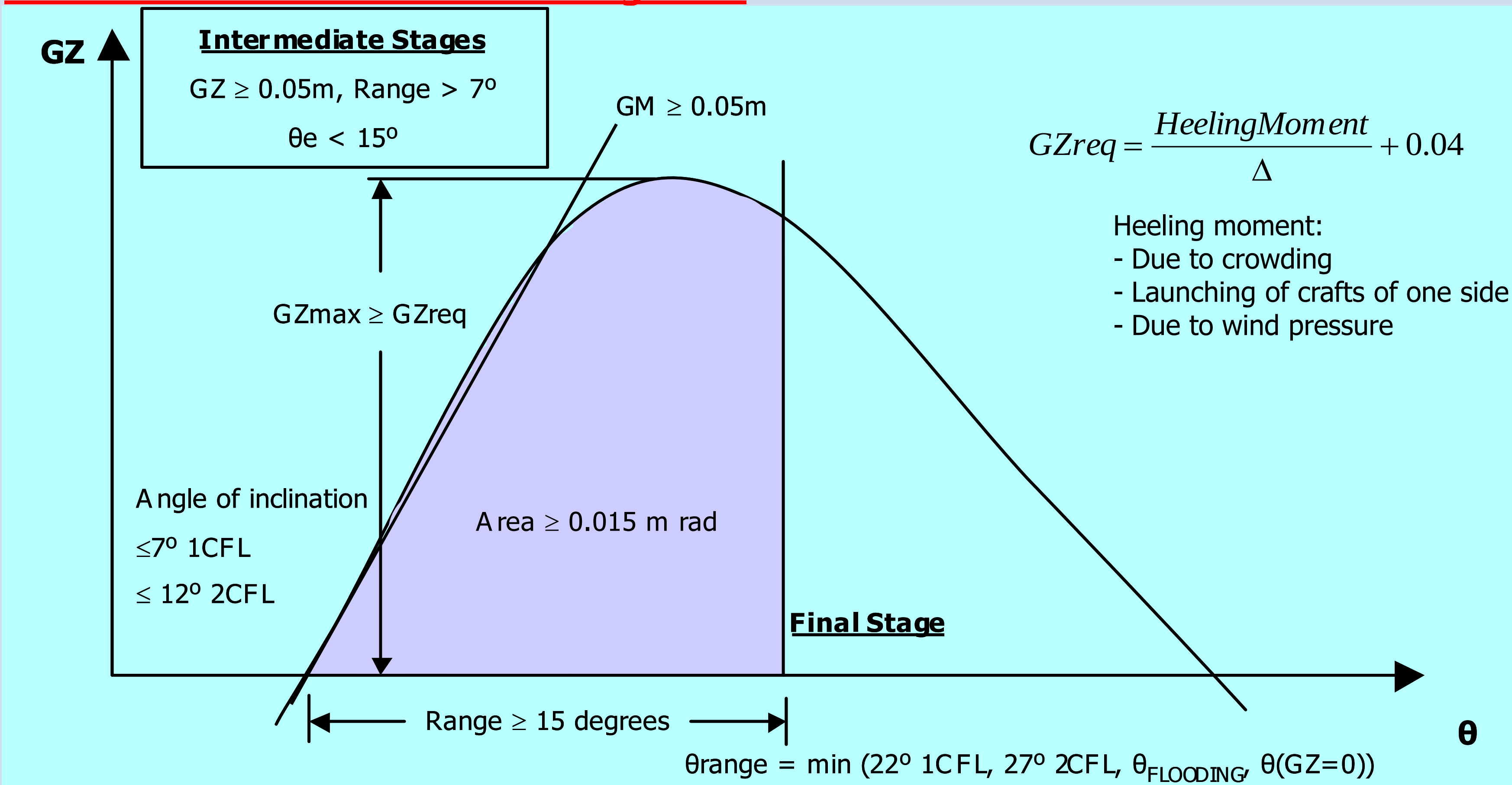
Main recent revisions of damage stability regulations for passenger and dry cargo ships.



Passenger ships (deterministic SOLAS 90 requirements)

Main damage stability criteria of SOLAS 90 for passenger ships

Examine for the maximum loading draft



RoPax – Ro-Ro passenger ships (deterministic-performance based)

Water On Deck

Stockholm Agreement-Resolution 14: for NW Europe (after the Estonia Accident)

EU Directive 2003/25/EC: for South Europe (after the SAMINA accident)

- In addition to the previously mentioned SOLAS 90 criteria, RoPax ships need to fulfill the same criteria, assuming certain amount of WOD (Water On Deck, namely their car deck)

-This hypothetical flood water mass is function of

- Damage freeboard
- Significant wave height in the area of operation
- Max flood water mass:
  - *0.5m for 4.0m sign. wave height and 0.5m damage freeboard*

RoPax – Ro-Ro passenger ships (deterministic-performance based)

Water On Deck

-Calculatory method: formal compliance with the specified regulation

Alternatively (equivalent model test method, Res. 14),

- Model tests with model of damaged ship in side waves: equivalent model test method, performance-based

-Generally: it proves in practice that the formal calculatory method is by far more onerous (very conservative) with respect to ship's survival conditions. Thus, the equivalent model test method is mostly preferred

Deterministic or Probabilistic Approach?!
Harmonization of existing & new damage stability regulations

The harmonization of existing damage stability rules was decided by IMO and led to a **unified assessment framework based on the probabilistic concept of estimating the damage stability of dry cargo and passenger ships**.

The main goal of harmonization referred to the **definition of survivability levels for dry cargo and passenger ships that are equivalent to those defined by the at that time in-force regulations for new-buildings.**

The outcome of the harmonization process was SOLAS 2009!

Status at that time (years 2000-2003, project HARDER)

Basic ship type	In force regulation	Model
Dry cargo ships	SOLAS B-1	Probabilistic
Passenger ships	Resolution A.265	Probabilistic
Passenger ships	SOLAS 90 (SOLAS 95)	Deterministic

REFERENCE: MSC1/Circ. 1226 (2007): Interim explanatory notes to the SOLAS Chapter II-1 Subdivision and damage Stability Regulations

SOLAS 2009 – Damage stability

Calculation of the attained subdivision index A

$$A_i = \sum_{j=1}^{j=t} P_j \cdot v_j \cdot s_j$$

Pi-factor: Probability that only the compartment or group of compartments under consideration may be flooded.

- *Maximum damage length changed <u>to 60</u> m in SOLAS 2009 (noting that it was 3%L + 3m, but not more than 11m in SOLAS 90!).*
- *Damages of up to B/2 should be assumed (allowing penetration of longitudinal centre line bulkheads)*

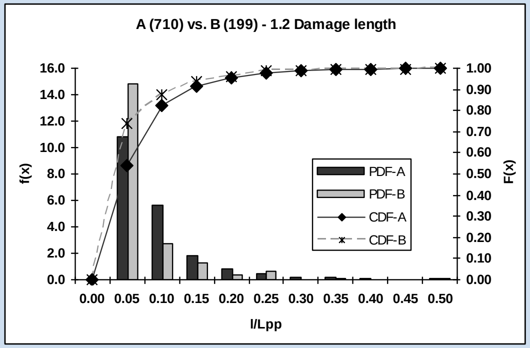
<u>REFERENCE:</u> MSC1/Circ. 1226 (2007): Interim explanatory notes to the SOLAS Chapter II-1 Subdivision and damage Stability Regulations

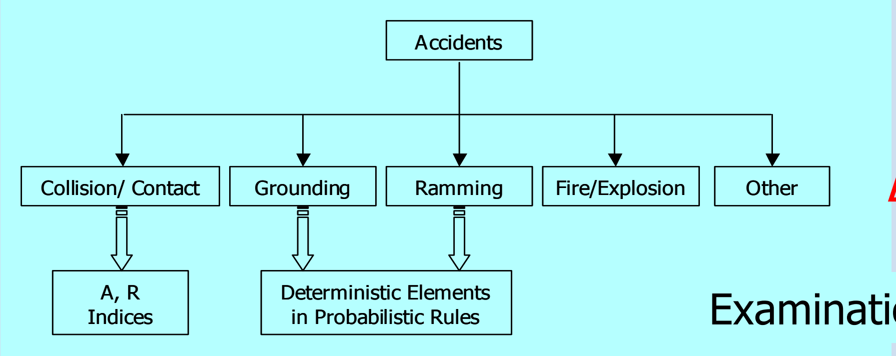
Details of Probabilistic Model

Basic Approach

Probabilistic Analysis of damage survivability

- Probability that the ship will encounter damage, P1
- Probability of the resulting damage location and extent, P2
- Probability of the ship surviving the damage, P3

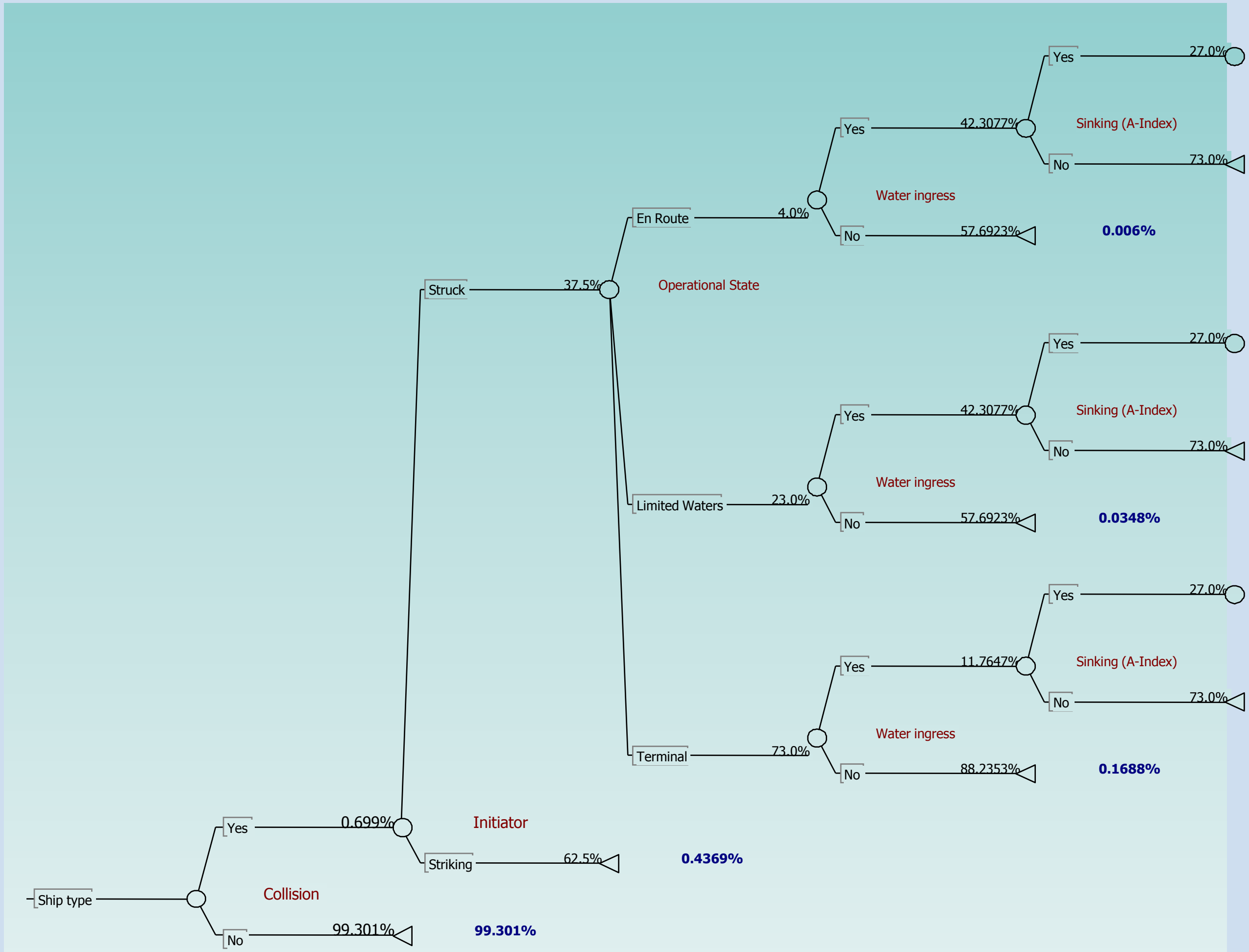




Loss of Watertight Integrity

Examination of probable damage scenarios

Risk Model (Event Tree) for collisions of cruise ships



Fast sinking: 18%
Fatalities: 80%

Slow sinking: 72%
Fatalities: 5%

Probabilistic Model

The probability of survival of a ship after a damage (LOWI) due to collision with another ship of comparable size is expressed by the Attained Subdivision Index A. When calculating this index, a series of different damage scenarios for pre-determined loading conditions (full and partial load) are taken into account. The general form of the index A is the following:

$$A = \sum wf_i \cdot A_i$$

Summation of attained indices for various loading conditions:
A = 0.4As + 0.4Ap + 0.2Al

wf_i: weight functions for the various loading conditions (full, partial, light)
A_i : attained subdivision index for each examined loading draft

The attained subdivision index should not be less that the required index R, which is specified in the SOLAS regulations.

Required Index R

1. Cargo ships, function of L
2. Passenger ships, function of L, number of POB N and N1 (lifeboat capacity)

$$R = 1 - \frac{C_1}{L_S + C_2 \cdot N + C_3}$$

Dry Cargo Ships (L>100m): C1=128, C2=0, C3=152.
Passenger Ships: C1=5000, C2=2.5, C3=15225.

Modelling of survivability levels

*The general formulation of new required survivability levels (project **HARDER**)*

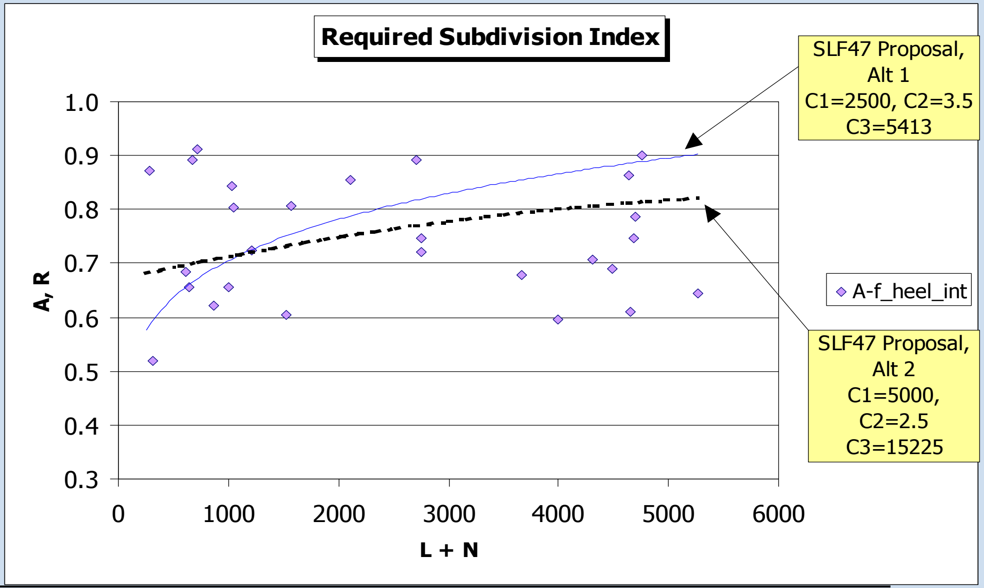
$$R = 1 - \frac{C_1}{L_S + C_2 \cdot N + C_3}$$

Following a series of deliberations at IMO-SLF-MSC, IMO-MSC80 (2005), the finally adopted the following numerals for the Ci coefficients

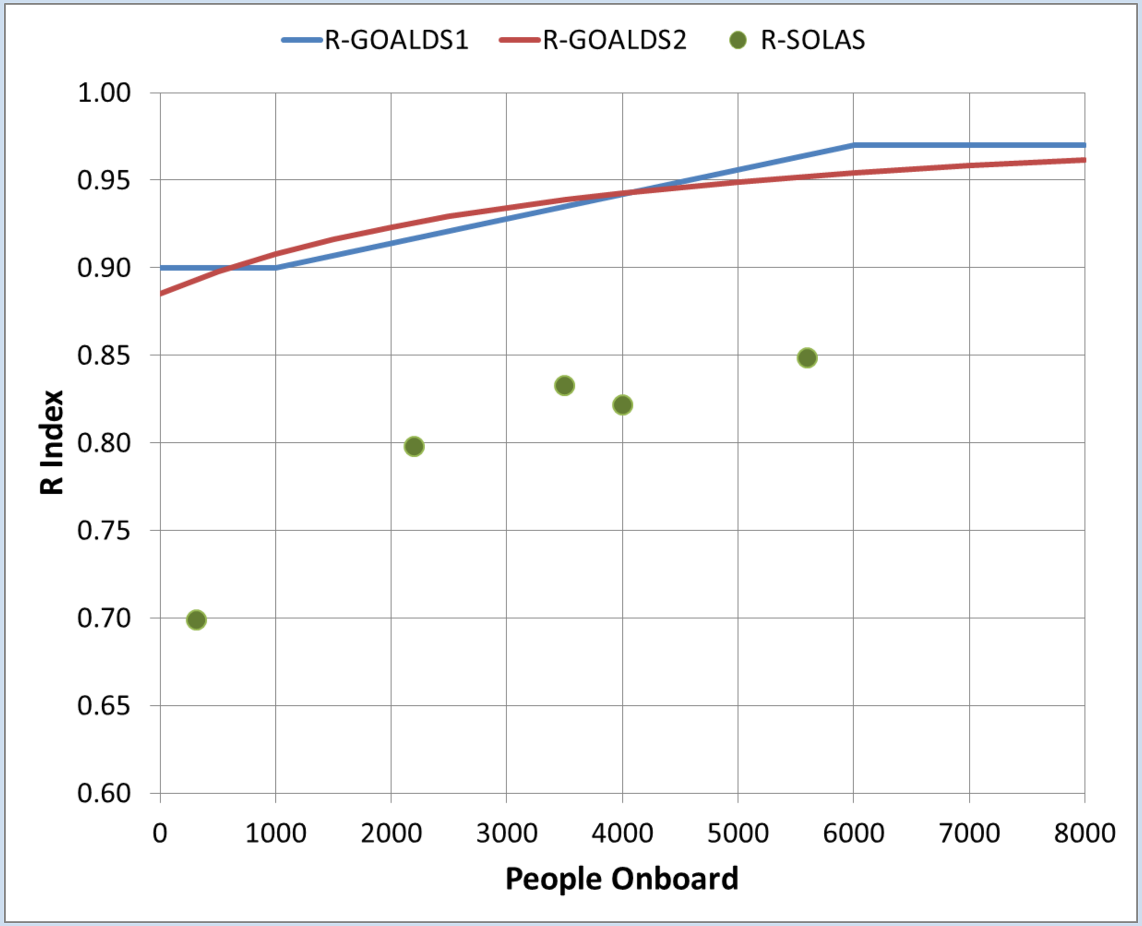
Dry Cargo Ships (L>100m): C1=128, C2=0, C3=152.

Passenger Ships: C1=5000, C2=2.5, C3=15225.

It should be noted, that due to the large scatter of the sample data of passenger ships, part of which were exhibiting unacceptably low attained indices, two alternative formulations for the R index were originally proposed by SLF47 for adoption by MSC 80. Alternative 1 corresponds to the best regression fitting of a reduced sample of ships with satisfactory levels of survivability, whereas Alternative 2 (*finally adopted*) considers an enhanced sample of passenger ships at worse regression fitting.



Comparison of Required Subdivision Indices



$$R_{Index1} = \begin{cases} 0.9 \text{ for } pob < 1{,}000 \\ \\ 0.97 \text{ for } pob \geq 6{,}000 \end{cases}$$

$$R_{Index2} = 1 - \left(\frac{2300}{5 \cdot pob + 20000} \right)$$

Pending final discussions/approval by IMO