# PERMEABLE VOLUME – THE FORGOTTEN "GALAXY" IN SHIP DESIGN

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## *ABSTRACT*

*Ships are designed based on three basic objectives pertaining to ship performance, functionally and safety, all dictated by external shape, internal layout, deadweight, payload, permeable volume, and their distributions. All, except for one, are calculated to extremely small tolerances and are subjected to rules and regulations that have been evolving for thousands of years. The exception is "permeable volume", (the internal free space in the ship hull and superstructure available for flooding), which is of the same magnitude as weight and buoyancy. Over the years, some generalised approximations have been adopted for principal ship spaces without differentiating between ship types, leading to gross approximations when calculating ship damage stability. In the latter case, the amount and distribution of residual permeable volume (together with buoyancy and weight), dictate whether a ship may sink because of inadequate buoyancy or capsize due to loss of stability. Yet, whilst all pertinent parameters are calculated to extreme accuracy, permeable volume and its distribution is calculated with naïve approximation. To demonstrate the impact of such approximations several passenger ships are considered in the paper, covering the whole range of ships in operation, and a sensitivity analysis is undertaking addressing the main ship spaces and their contribution to permeable volume, offering unique insight on the key influence of permeability on ship damage stability. Building on this, the impact of permeability as a key design option to affect life-cycle stability management is elaborated and demonstrated, leading to conclusions and recommendations.*

## KEY WORDS

Permeability in ship design, key influencing factors, damage stability, life-cycle stability management, safety

## INTRODUCTION

In Naval Architecture lexicon, permeability (μ) is regarded as the fraction of floodable volume of a room to that of its overall volume or put simply, the percentage of the free space of a room. A simplified equation to represent permeability at ship level is depicted in Equation 1.

$$\mu = \frac{\text{Floodable volume}}{\text{Total volume}} = \frac{V_{\text{floodable}}}{V_{\text{total}}} \qquad [1]$$

In this respect, the assumptions within the probabilistic framework concerning the adopted values for permeability as outlined within SOLAS 2009, lack due consideration concerning the impact of this primary ship property on ship stability and safety. Considering that ship weight and buoyancy are calculated with accuracy reflected in decimals, permeability is defined in terms of gross percentages. The current damage stability framework for passenger ships, namely SOLAS (IMO, 2009) specifies values for three different compartment types, namely accommodation or voids, machinery and stores with designated values

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of 0.95, 0.85 and 0.60 respectively. These values account for the volume and manner in which various items are distributed within each different type of space, accounting for the nature of the items themselves. The values are applicable to all passenger ships carrying more than 12 passengers on international voyages. However, considering the number, size and type of passenger ships encountered currently in operation, it is difficult to comprehend such generalisations.

Understandably, the impact and consequences of permeability pertaining to damage stability is key. Notwithstanding this, there is scarce evidence to justify how the permeability values in use in SOLAS were established. More surprisingly, the current regulations imply that RoPax, dry cargo, tankers and cruise vessels are assessed using the same permeability values for the main four space types being considered despite the fact that these ship types are known to have very different properties when it comes to their internal arrangement, SOLAS and MARPOL (IMO, 2009, IMO, 2004), respectively. Large passenger ships are known to have very complex internal arrangements with over-polished accommodation spaces and galleys, filled with furniture and appliances, whereas dry cargo ships have simplified accommodation spaces and overpacked machinery spaces. Historically, the values of permeability were introduced initially in 1912 as part of the first Committee on Safety of Construction (CSC, 1913) and they have been widely used ever since. These are retrospectively applied over the past century, and are paved through the treaty series of (UKG, 1929), (UKG, 1948), (UKG, 1960) and (IMCO, 1973) respectively leading to the current framework (IMO, 2009). The various established norms have no provisions for utilisation of actual data but instead support the utilisation of the first adopted arbitrary values, in principle ignoring how ship technology, design and equipment have changed and advanced significantly over the years. Smaller boilers, compact cable, and pipe units reduced size of gearboxes and pumps, alternative fuel tanks, innovative electric propulsion units, scrubbers and modern packed furniture with smaller volumes are a few examples of the technological advances that have gained momentum over the years. Moreover, the industry is currently employing cutting edge technology and it will be a relatively simple exercise to establish representative permeability values for the ship types being considered. However, any changes in SOLAS, especially those affecting established fundamental values and principles, as currently being adopted, will be a “tough nut to crack”, as they would need to go through recent practices on Novel Technology Qualification and Alternative Design and Arrangements approvals (DNV GL 2015), a very tedious and exhaustive route that instead of nurturing innovation as initially intended, they stifle progress, even when considering that simplest of changes, such as permeability in designated ship spaces, even when unshakable evidence is presented.

Building on the above, this paper aims to demonstrate the importance of permeability on the damage of passenger ships by using pertinent sample ships. More specifically, damage stability calculations (A-Index) are conducted to provide indicative measures on the impact of permeability by addressing local and global ship perspectives. This is then used as the basis for addressing wider issues in ship design and operation, pertaining to life-cycle damage stability management.

## ASSUMPTIONS ON PERMEABILITY IN DAMAGE STABILITY ASSESSMENT

In early design stage, values of permeability are assigned in the form of room purposes, following completion of the design arrangements where such decisions are made. These in turn, are connected to various assumptions that have serious bearing on the manner in which permeability serves the reflected volumes and the way in which they are considered within the damage stability assessment process. To start with, one of the main properties concerns the level of uniformity and density of the volume in any room under consideration. Typically, a volume can have either homogeneous or heterogeneous properties (Kantzas et al., 2016). The former signifies that the components of a space have the same proportions throughout the space and these will follow the same pattern if segregated into any way. In this respect, the permeability of a room has one value, uniformly across the entire space without being subjected to any deviations. Whilst this is time efficient in performing calculations, it is an inadequate way of representing the actual distribution of contents within such space. In this respect, whilst a change in the level of the water inside a flooded compartment will influence the value of permeability as the floodable volume changes but not the associated properties pertaining to the room and its components. However, these can influence the way the water progresses to adjacent spaces through the leakage area and time (Ruponen, 2017). In this respect, a number of studies (Illario, 2014), (Vassalos et al., 2016), have demonstrated that considering homogeneous permeability in damage stability assessment could have a serious impact on the results.

Moreover, a heterogeneous space entails that the comprising components are not uniformly distributed across the entire space, and this might lead to local regions with distinct properties. In this case, the volume of a space needs to be partitioned as a number of smaller cubicles, each with different permeability than the reference room. This means that the distribution of floodwater in a room will differ since the centre of gravity of the overall fluid mass will be different. Moreover, heterogeneous spaces could also affect damaged ship motions in that it can cause excessive heeling because of uneven floodwater distribution, leading to large angles of heel and roll motion, especially when the space in question is above the subdivision deck. Related literature, (Santos and Soares, 2009), demonstrates the applicability of a space permeability partitioning in a machinery space.

Another important element in this direction is the classification of items and their respective permeability. However, this is entirely dependent on the modelling detail of the rooms under consideration. Usually, the designs are kept to a simplistic degree of detail in addressing damage stability assessment. Different properties such as friction, resistance, and geometric coefficients for different materials in each space will have bearing on the way the properties of the overall room permeability changes with time, which in turn, will affect sloshing, compressibility and free surface effects. In the current instruments of damage stability assessment, the designer has the capacity of selecting across a range of designated purposes fit for specific rooms in the arrangement that are associated with various permeability values accordingly. In turn, these fall under one of the primary permeability groups indicated earlier. One example relates to the store spaces where hospital, laundry, machinery, luggage, and kitchen supply stores are under the same primary permeability group and assigned a value of 0.60. One could understand that even though the spaces relate to stores, they enclose various materials with different properties and as a result they do not capture the actual permeable volume in an effective manner.

As demonstrated in Figure 1, six cruise ships have undergone a sensitivity analysis. The ships represent a reflective sample of the current fleet concerning size and capacity. Indicatively, the vessels vary from 60 to 320 metres in length and in total volume for the different category of spaces from 850 $m^3$ to 40,900 $m^3$ for machinery, 1,000 $m^3$ to 65,000 $m^3$ for accommodation and 300 $m^3$ to 13,000 $m^3$ for store spaces, respectively.

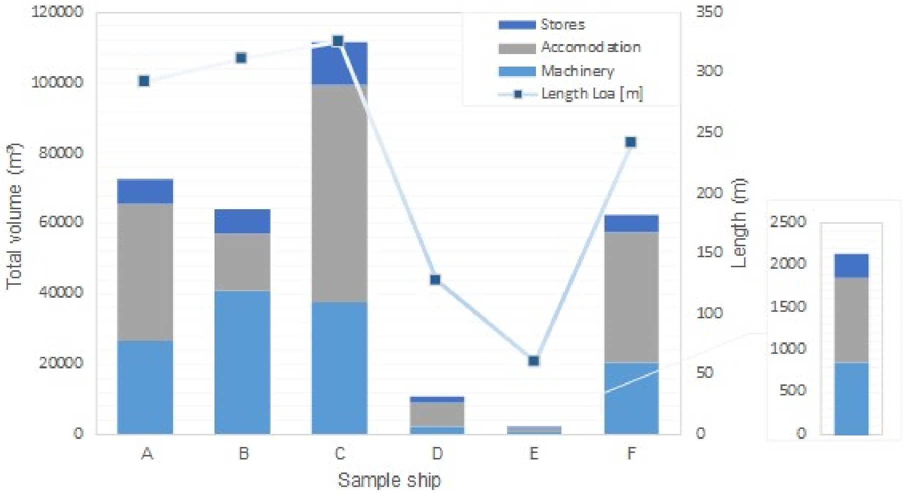

**Figure 1: Permeable volume distribution for machinery, accommodation and store spaces for vessels used in the sensitivity analysis.**

The assumptions made during the design phase shape safety over the whole life cycle. This may be done incrementally, with simpler tools at the initial stages, then progressively introducing more advanced tools as design matures. In this paper, the impact of permeability is investigated though employing SOLAS static calculations for assessing the Attained Subdivision Index (A-Index).

## Parametric Investigation on principal permeability parameters

In the study presented in this paper, static stability calculations are undertaken, pertaining to the A-Index with varying permeability across the three different permeability groups. This entails generating collision damage scenarios deriving from SOLAS-related accident statistics (IMO, 2009). The calculations are performed using NAPA software, which facilitates automatic alteration of permeability values and identifies and categorises rooms and compartments based on their intended purpose. In this, the calculations are restricted to the watertight envelope, which may include an additional deck above the subdivision deck. In this respect, accommodation and store spaces above this envelope are omitted. The graphs presented in Figure 2 on the following page, demonstrate the results obtained for all the sample ships under consideration. Here, it is shown that the change in the total A-Index follows a linear trend across varying permeability in each case and the impact on each vessel is consistent, concerning their respective floodable volume.

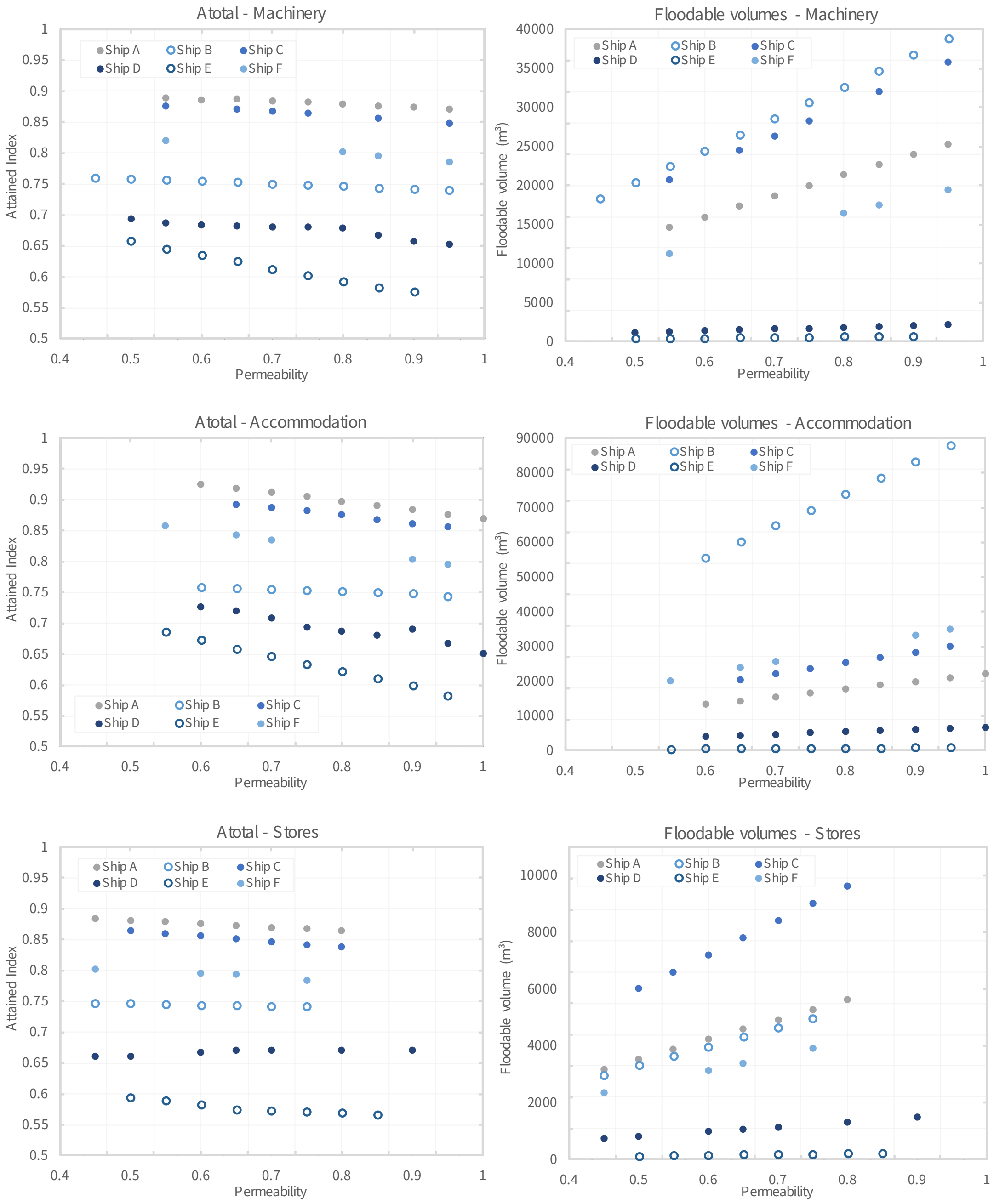

**Figure 2: Impact of varying permeability for principal spaces on A-Index**

In the case of machinery, the two smaller ships (E and D) exhibit a lower A-Index, below 0.69, representing their relatively small machinery spaces with volume 425 to 2,000 $m^3$ as opposed to the large ships with volume higher than 15,000 $m^3$ and an A-Index as high as 0.89. The accommodations present a steeper decremented tendency towards higher permeability, showing more sensitivity. This is due to the location of the accommodation spaces, as for example the large ship C relates to an accommodation volume of 20,500 $m^3$ in comparison to the smaller ship D with volume of 4,000 $m^3$. Despite the dominant role of the total floodable volume in this sensitivity analysis, the location of the spaces is also significant. In the case of store spaces, the impact is reflective of the floodable volumes. The largest of the ships (A and C) attains an A-Index from 0.83 to 0.88 for volumes of 5,600 to 9,600 $m^3$, respectively, whilst the smallest ship (E) the A-Index reaches a low of 0.60. The sensitivity in the graphs is ascertained via the slope in the change of the total A-Index as a function of change in permeability, see Figure 3. The origin of the graph depicts the default value as stipulated by SOLAS.

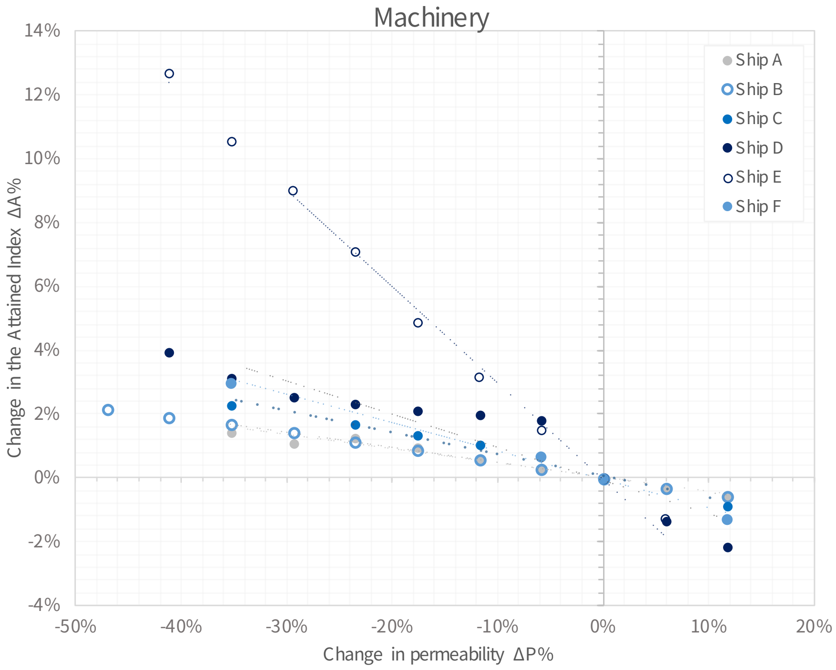

**Figure 3: Change in the total A-Index versus change in permeability in machinery spaces**

In Figure 3, the smallest ship E exhibits the highest change across the sample ships in the case of machinery spaces with a slope of 0.30. This means that for 10% change in permeability there is 3% change in the A-Index, which in turn can be proven significant to the case of smaller ships. Generally, all the machinery spaces are located within the watertight envelope while the accommodation spaces are scattered. Saying this, the impact on A-Index from machinery ranges between 1.5 and 4% but in the case of accommodation around 2 and 8% which, as expected, justifies the situation.

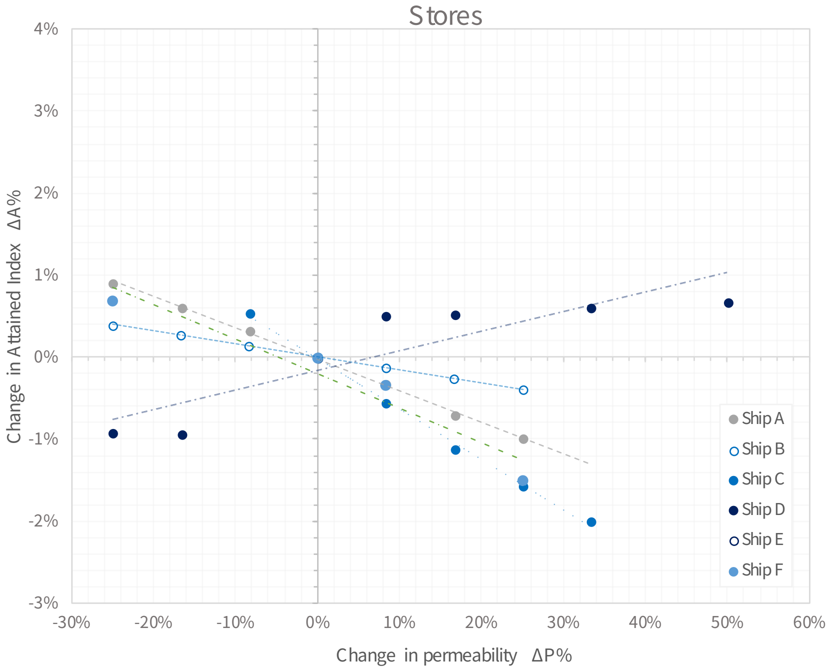

**Figure 4: Change in the total Attained Index versus the change in permeability in percentage for conduction of permeability variation in store spaces. The origin represents the default value 0.60 as per SOLAS.**

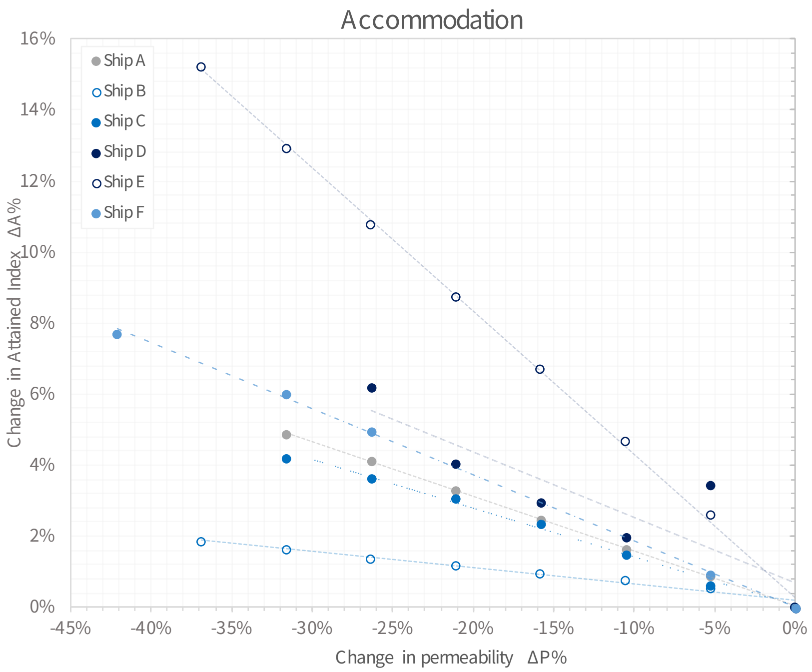

**Figure 5: Change in the total A-Index versus the change in permeability in percentage for conduction of permeability variation in accommodation spaces. The origin represents the default value 0.95 as per SOLAS.**

Figure 5 demonstrates that the impact of the store spaces is small compared to accommodation spaces, Figure 4, and machinery spaces. More specifically, ship E demonstrates a 10% change in the A-Index with a 20% reduction in permeability. Ship A, on the other hand incurs only a 5% change in the A-Index with a 25% reduction of the initial permeability. A noticeable trend that deviates from the other ships is observed in the case of ship D with varying permeability in the store spaces. The justification behind this lies in the asymmetrical location of the store spaces on the starboard side that leads to excessive heel when flooded. As expected, the available floodable volume is the main influential parameter impacting permeability.

## IMPACT OF PERMEABILITY ON LIFE-CYCLE STABIITY MANAGEMENT

In the absence of accurate predictions for ship stability deterioration over the life cycle of passenger ships, the need for a structured approach to addressing this problem is paramount. More specifically, allowing for arbitrary stability margins at the design stage to account for this effect, leads to either unrealistically large margins, which penalise the ship over the life cycle or worse to inadequate margins, which would severely affect ship operation or lead to unsafe operation. This, in turn, would have a serious impact on business. Undoubtedly, designing a ship with compliant damage stability requirements, monitoring stability deterioration during, for example, annual surveys and “boosting up” GM as may be required would address all problems in the most-efficient way. This “boosting up” of GM relates to a recent technological innovation, as described next, which is built on careful consideration of the permeable volume onboard ships and its impact on ships stability.

### Adaptive Reconfigurable Safety Technology (AREST) Systems

Recent technological developments deriving from five years of research and application at Strathclyde University, suggests the use of high expansion foam as a means of changing the permeable volume and its distribution within ships either during design or as an effective means for emergency response in flooding emergencies, hence for life-cycle stability management, (Patterson, 2020). One of the options includes the deployment of high expansion foam in selected vulnerable spaces in the ship as a means of passive/active protection. The concept has been tested through several feasibility studies with industry, involving new designs and existing ships and is currently undergoing approvals by class and administration whilst the offering for industry applications involves partnerships with the multi-national foam manufacturer MINOVA and the Australian design office, Sea Transport Solutions.

### The Concept

The passive flooding protection system involves the installation of permanent foam in void spaces (changing the permeability in such spaces) to provide additional reserve buoyancy when these spaces are damaged following a flooding incident, which, in turn leads to increasing damage GM. Such installations act much like buoyancy tanks with impermeable volume to provide buoyancy within the immediate damaged area, Figure 6. Upon installation, the foam adheres to the vessel steel structure and acts as a protective/anti-corrosive coating, prohibiting build-up of moisture between foam and ship structure and offering effective insulation. The foam is resilient and will last, without degradation, for the vessel life span. Moreover, the same concept being used to address the design of newbuildings will enable attention to all existing ships, which are currently operating at inferior stability standards, a hiccup in maritime legislation known as the “Grandfather Clause”.

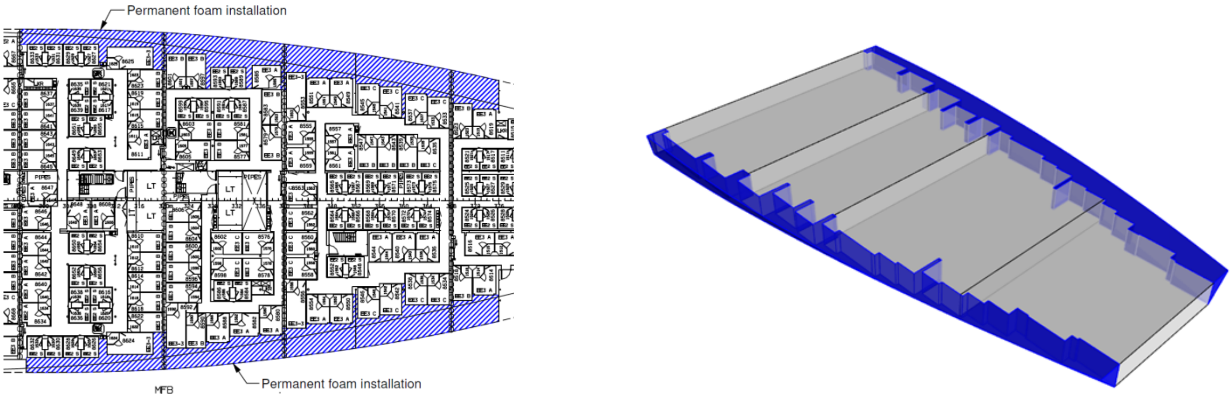

**Figure 6: Foam installation (permeability change) in void spaces in the wing compartments of a cruise ship**

## CASE STUDY – LARGE CRUISE VESSEL (Vassalos et al., 2021)

This section provides an overview of the methodology adopted and supporting calculations in the assessment of the effectiveness of the proposed use of foam for filing void spaces (changing permeable volume) as a means of improving damage stability. For this purpose, a cruise vessel is subjected to probabilistic damage stability assessment in accordance with (IMO MSC.216(82), 2006); (SOLAS, 2009). The improvement afforded by the fixed foam installations has been measured in terms of increased GM margins as opposed to other metrics such as ΔPLL or ΔA-Index. The reason for this is simply that, from an operator’s perspective, the former is the most important and familiar measurement with direct impact on the operability of their vessels. An overview of the vessel particulars and loading conditions examined is provided within Table 1 and Table 2, respectively.

**Table 1: Case Study Vessel Particulars**

| **Cruise Ship C1 – Principal Particulars** | | | |
|---|---|---|---|
| Ship’s name | C1 | Draught, subdivision | 8.6 m |
| Length OA | 317.2 m | Draught, design | 7.3 m |
| Length BP | 293.7 m | No. Passengers | 3148 p. |
| Breadth, moulded | 36.8 m | No. Crew | 1252 p. |

**Table 2: Loading Conditions Considered**

| **Parameter** | **Unit** | **dl** | **dp** | **ds** |
|---|---|---|---|---|
| T0 | m | 8.6 | 8.36 | 8 |
| TR0 | m | 0 | 0 | 0.3 |
| GM0 | m | 2.64 | 2.49 | 2.57 |
| KG | m | 17.92 | 18.29 | 18.61 |

| | | | | |
|---|---|---|---|---|
| Displacement | t | 61520 | 59234 | 56023 |

The ship model used in the damage stability calculations consists of the following buoyant volumes:

- Hull from base line to DK6 (Deck 4, 17.3m above base)
- Two pods
- Two foils

The following volumes are deducted from the buoyant volume:

- Three bow thruster tunnels
- One anti-suction tunnel
- Six sea chests

The vessel has been assessed such that the A-Index is not less than the Required Subdivision Index (R-Index) as calculated according to equation 2.

$$R = 1 - \frac{5000}{L_S + 2.5 \cdot N + 15225} \qquad [2]$$

Where,
$N_1$ – number of persons for whom lifeboats are provided
$N_1 = 3300$
$N_2$ – number of persons that the ship is permitted to carry in excess of $N_1$
$N_2 = 1101$
$N = N_1+2N_2$
$N = 5502$
$L_S = 316.19$ m

**Permeabilities**

The permeability values used in the assessment have been defined in one of two ways. Firstly, those spaces not influenced by the AREST system have been assigned permeability values in line with conventional SOLAS assumptions, Table 3.

**Table 3: SOLAS 2009 Space Permeability Assumptions**

| **Spaces** | **Permeability** |
|---|---|
| Appropriated to stores | 0.60 |
| Occupied by accommodation | 0.95 |
| Occupied by machinery | 0.85 |
| Intended for liquids | 0.95 |
| Void spaces | 0.95 |
| Permanent Foam Installations | 0.00 |

However, in such cases that fixed foam installations have been assumed to be in effect, the permeability of the protected space has been altered not in the traditional sense (i.e., homogenous reduction), but instead by modelling the foam installation as a separate volume of permeability 0.05 as shown in Figure 6 and justified in (Paterson, 2020). In general, the assumptions made in assessing the impact of the permanent foam installations as a permeability reduction are in line with (MSC Res.216(82), 2006); (SOLAS Regulation 7-3.3, 2009), where it is stated that “Other figures for permeability may be used if substantiated by calculations”.

## Damage Stability Calculations and GM Margins As-Built

### *Calculation of A-Index*

Based on the assumptions outlined within the foregoing, Table 4 outlined the A-Index calculation results for the vessel in her as-built condition. Here we can observe that as the limiting GM values have been used within the calculation, the A-Index narrowly exceeds the Required Index, as should be expected.

**Table 4: As-built A-Index Calculation**

| ID | T(m) | TR(m) | GM(m) | A | w | A*w |
|---|---|---|---|---|---|---|
| DL | 8.00 | 0.30 | 2.57 | 0.846 | 0.2 | 0.1692 |
| DP | 8.36 | 0.00 | 2.49 | 0.829 | 0.4 | 0.3315 |
| DS | 8.60 | 0.00 | 2.64 | 0.822 | 0.4 | 0.3289 |
| | | | | | Attained Index | 0.830 |
| | | | | | Required Index | 0.829 |

### *Calculation of GM Margins*

The presented limiting curve and loading conditions are based on the cruise ship stability booklet. Observation of the vessel GM limit curve highlights that GM margins in some 40% of cases lie below 10 cm, see Figure 7. By predicting an annual increase in vessel Lightweight KG by 2 cm (in line with previous growth trends), additional GM margins of approximately 35 cm for all loading cases are required to remain compliant in the 20-years' time being planned. This has been estimated using a constant lightweight value but having altered the vertical centre of gravity by 40 cm for each statutory loading condition, thereby accounting only for increased KG and not draught. The results of this process are summarised within Table 5, in terms of existing GM margins and those required in 20 years' time, following the predicted KG increase. From these results, it is clear that the vessel cannot, at present, support the resultant degradation in GM.

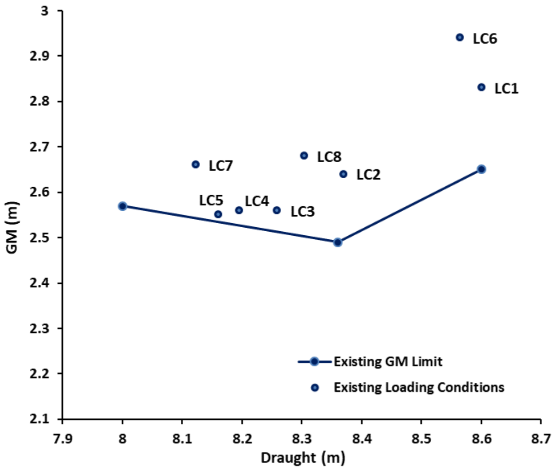

**Table 5. Loading condition overview & GM margins with Projected growth**

| ID | Description | T(m) | GM (m) | GM Req. (m) | GM Margin (m) | ΔGM (20 yr. growth) |
|---|---|---|---|---|---|---|
| LC1 | 100% Cons Max. Draught | 8.601 | 2.83 | 2.65 | 0.18 | 0.337 |
| LC2 | 75% Bunkers and stores | 8.370 | 2.64 | 2.50 | 0.14 | 0.339 |
| LC3 | 50% Bunkers and stores | 8.259 | 2.56 | 2.51 | 0.05 | 0.360 |
| LC4 | 25% Bunkers and stores | 8.195 | 2.56 | 2.53 | 0.03 | 0.358 |
| LC5 | Arrival Condition | 8.160 | 2.55 | 2.54 | 0.01 | 0.355 |
| LC6 | Ballast Departure Condition | 8.565 | 2.94 | 2.62 | 0.32 | 0.337 |
| LC7 | Ballast Arrival Condition | 8.123 | 2.66 | 2.55 | 0.11 | 0.356 |

| | | | | | | |
|---|---|---|---|---|---|---|
| LC8 | Docking Condition | 8.304 | 2.68 | 2.51 | 0.17 | 0.347 |

### Permanent Foam Installations

The following provides a summary of all proposed permanent foam installation locations as shown in Figure 7 and Table 6. In addition, a breakdown of all foam volumes and installation weights is provided within Table 6. The location of the foam installations has been focused within areas found to possess the highest flooding risk. The foam has also been located predominantly around Decks 1 & 2, which lie within the region of the damaged waterline and above, thus providing both buoyancy and stability at equilibrium and as the vessel is heeled from this position.

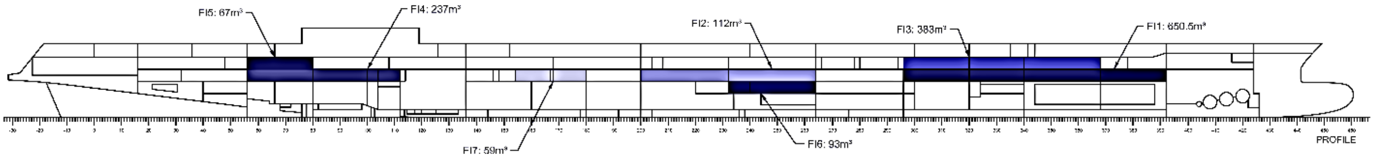

Figure 7: Foam Installation Locations

Table 6: Foam Installation volumes and weights

| Foam Application | Foam volume (m$^3$) | Weight (Tonnes) |
|---|---|---|
| 1 | 651 | 8.131 |
| 2 | 112 | 1.400 |
| 3 | 383 | 4.788 |
| 4 | 237 | 2.963 |
| 5 | 67 | 0.838 |
| 6 | 93 | 1.163 |
| 7 | 59 | 0.738 |
| Total | 1601.5 | 20.019 |

### Updated A-Index Calculation and GM Margins – With permanent foam installations

Following re-modelling of the vessel internal geometry such as to account for the foam modifications, the vessel damage stability performance has been re-assessed to ascertain the improvement in GM margins. A summary of the re-assessed A-Index calculation is shown within Table 7, again conducted such that A=R, thus providing the widest GM margins. In addition, the resultant limiting GM values and margins are provided within Table 8 for all statutory loading conditions.

Table 7: Attained Index Calculation with modifications & reduced GM

| | T(m) | TR(m) | GM(m) | A | w | A*w |
|---|---|---|---|---|---|---|
| DL | 8.00 | 0.30 | 2.400 | 0.840 | 0.2 | 0.1680 |
| DP | 8.36 | 0.00 | 2.280 | 0.822 | 0.4 | 0.3286 |
| DS | 8.60 | 0.00 | 2.490 | 0.831 | 0.4 | 0.3323 |
| | | | | | Attained Index | 0.829 |
| | | | | | Required Index | 0.829 |

Table 8. Comparison of GM margins

| | | Existing | | With AREST | |
|---|---|---|---|---|---|
| ID | GM (m) | GM Req. (m) | GM Margin (m) | GM Req. (m) | GM Margin (m) |
| LC1 | 2.83 | 2.65 | 0.18 | 2.491 | 0.339 |
| LC2 | 2.64 | 2.5 | 0.14 | 2.289 | 0.351 |
| LC3 | 2.56 | 2.51 | 0.05 | 2.314 | 0.246 |

| | | | | | |
|---|---|---|---|---|---|
| LC4 | 2.56 | 2.53 | 0.03 | 2.335 | 0.225 |
| LC5 | 2.55 | 2.54 | 0.01 | 2.347 | 0.203 |
| LC6 | 2.94 | 2.62 | 0.32 | 2.459 | 0.481 |
| LC7 | 2.66 | 2.55 | 0.11 | 2.359 | 0.301 |
| LC8 | 2.68 | 2.51 | 0.17 | 2.299 | 0.381 |

As can be observed within Table 8, Following the proposed modifications, GM Margins have been increased between 16cm - 21cm, with the resultant margins now ranging between 20 cm – 48 cm. With consideration of the projected growth in vessel lightweight KG of 2cm/year, 50% of statutory loading conditions can now survive this growth without jeopardising compliance, see Figure 12.

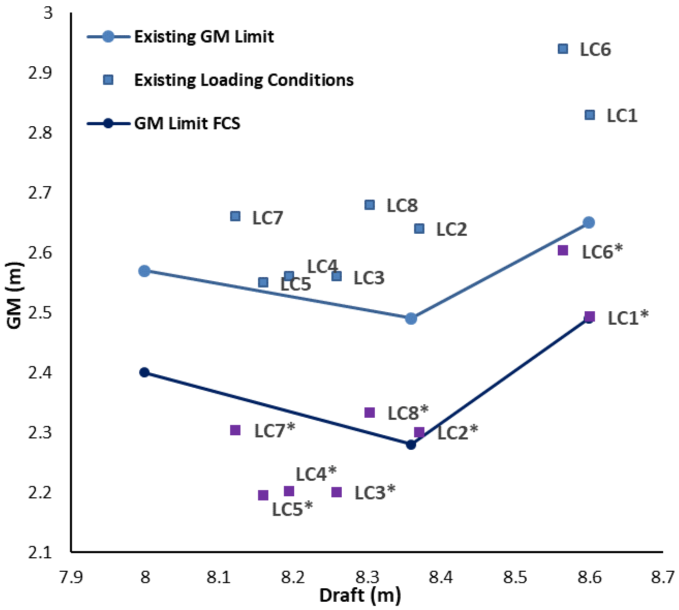

**Figure 12. Updated GM Limit Curve (with AREST) & Loading conditions (following 20 yrs. KG increase)**

## CONCLUSIONS

Based on the work presented in the foregoing and the review of developments on the subject, the following concluding remarks can be drawn:

- Stemming from the logical deduction that if permeable volume in ships is of the same order of magnitude as weight and buoyancy then it should be addressed with the same scrutiny and accuracy. To address this issue systematically, a parametric investigation has been conducted, using several cruise ships, and considering the impact of changing permeability in these spaces on the A-Index of subdivision, as described in standard IMO instruments for ship damage stability.
- The results of this investigation clearly show that cruise ships are vulnerable to large increments in permeability. Particularly, a maximum change in the A-Index of the order of 17.7% is observed in the case of accommodation, 2.9% in the case of stores and finally 12.7% in the case of store spaces.
- The results further indicate that the impact of changing permeability in the accommodation spaces is larger than for the machinery spaces whilst the impact from stores is proven to be insignificant. That is because the accommodation spaces are scattered along the length of the vessel and in locations above the watertight deck, thus leading to large heeling angles in case of flooding. In fact, the smaller the length and volume of displacement of the vessel, the higher the impact on the A-Index.

- As a general remark, permeable volume plays a vital role in either case as it affects dramatically the slope of change of the A-Index to changes of permeability. This is related to the size of the vessel and watertight arrangements and is ship specific.
- Considering the impact of permeability in ships on damage stability, led to an innovative solution that is likely to eradicate centuries-old problems and provide a platform for a rational approach to cost-effective stability management over the life cycle of the vessel. This entails a risk-informed reduction in permeable volume in selected void spaces within the ship construction by filling these with high expansion foam.
- Interestingly, most ships are being designed and built in a way that leads to considerable void spaces, which when flooded following a collision incident, cause asymmetric flooding, potentially during the transient phase and hence to rapid loss of the vessel.
- This design vulnerability could turn into a very effective passive flooding protection system with permanent foam installation in high-risk void spaces.

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