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PROJECT DELIVERABLE REPORT

Introducing advanced ICT
and Mass Evacuation Vessel design
to ship evacuation and rescue systems

PALAEMON MASS EVACUATION VESSEL

D4.4 MEV-II naval architecture and structural design

A holistic passenger ship evacuation and rescue ecosystem
MG-2-2-2018
Marine Accident Response

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Revision History

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0.1	2020/09/28	L. Herrera	
0.2	2020/09/28	E. Chatzidouros	MEV II Design
0.3	2020/010/28	Konstantinos Lousis Alexandros Michelis E. Chatzidouros	MEV II requirements – Version review
0.4	2021/03/11	E. Chatzidouros	MEV II structural design
0.5	2021/06/28	E. Chatzidouros	MEV II structural analysis considering new material properties of bio-composites
0.6	2021/09/02	E. Chatzidouros	MEV II structrural analysis using prepreg CFRP material properties
0.7	2021/10/15	Laura Herrera, E. Chatzidouros	Change in the design and access to MEV II from the ship
0.8	2021/11/01	Laura Herrera, E. Chatzidouros	Final draft for internal review

Contents

Abbreviations

CFRP	Carbon Fiber Reinforced Composites
CL	Center Line
FEA	Finite Element Analysis
ICT	Information Communication Technology
MEV	Mass Evacuation Vehicle
LB	Life Boat
LSA	Life-Saving Appliances
QFD	Quality Function Deployment
SOLAS	International Convention for the Safety of Life at Sea
SoA	State of the Art

1 Summary

This deliverable presents the conceptual design and analysis of the MEV-II that was performed taking into account the specifications and requirements set in WP2. The MEV-II is a novel ship evacuation vehicle, constructed of composite materials, designed to accommodate a very large number of passengers, and to have a power train capable of obtaining speeds of at least 5 knts. Furthermore, the MEV-II is a design intended for use by the future cruise and passenger ships, where the MEV-II will be an integrated part of the ship structure. In this context, the design of the MEV-II will represent a totally new concept.

The MEV-II will be studied in terms of stability, seakeeping, and structural response in adverse weather conditions or other adverse situations such as launching mishaps scenarios, which might compromise the structural integrity of the vehicle. A Finite Element Analysis (FEA) will be performed using the aforementioned scenarios as loading cases to study and optimize the structural design of the MEV-II. The structural design will take into account that the MEV-II will be manufactured using composites. Moreover, the MEV-II design will consider the usability of its structure as a part of the ship, the launching capabilities, and the performance and utility of the vehicle when in water.

The MEV-II will be designed by using a new conceptual cruise ship design as a basis. This evolutionary design will take into account that the MEV II will be a part of the ship's superstructure. Thus, a new cruise ship design is proposed in this task, taking into account the aforementioned concept. Within this concept, the MEV-II design will be evaluated under a numerical simulation environment.

The first phase of the design will deal with the naval architecture design of the MEV-II, following the specifications and requirements set in WP2, regarding the size and shape of the MEV-II. Special consideration will be given to the incorporation of the MEV-II as an integral part of the ship, but also to the launching system, and the MEV-II functions when sailing. The detailed structural design and analysis will be performed by following the relevant standards and guidelines and by using FEA of people inside the MEV-II. The structure definition process will take into account that the MEV-II will be constructed with composite materials. The structural design drawings of the MEV-II will be produced.

In D4.5 the stability, seakeeping, power train, and passenger space aspects of the vehicle, regarding the access, the general arrangement drawings and lines plan of the MEV-II will be accomplished in this task. Furthermore, numerical simulations of the launching and behavior of the MEV-II when in the water will be carried out. The MEV-II conceptual design will also include new ship designs or particularly extensive modifications on existing ship designs, which can accommodate the MEV-II concept.

2 Introduction

PALAEMON aims to address the increased need for advanced passenger ship evacuation methodologies by defining a new ICT framework and radical rethink of mass evacuation systems with the introduction of MEVs with a wider scope than a sole technical proposition.

The PALAEMON project proposition is two-fold. The first part is to replace the LBs carried at the side of the ship with a big composite floating structure serving as a MEV-I (D4.1). The second part is to design a whole new evacuation vehicle that will be part of the ship's structure, will have increased space for evacuating passengers and crew members, will enable easy launching from the ship.

The MEV-II will be a conceptual design with structural drawings and naval architectural studies, the concept will be tested in terms of simulations. The MEV-II targets future ship designs that will accommodate the LB, and be able to use the MEV-II for normal operations (i.e., as tender boats) and launching.

The MEV-II will be designed and simulated for:

- The launch process from the mother-vessel;
- Its seaworthiness;
- Its ability to navigate; and
- Structural Integrity.

In addition, the MEV-II will be used to study the interior spaces and layout. As specified by the end-users in WP2, the MEVs will be adaptable to each vessel (type) since the room for storage, the physical constraints for the launch and the number of passengers will be different.

A comparison study against a level-zero practice (level zero practice can be defined according to the current procedures and guidelines in practice) will be carried out.

A prototype design will be developed and tested in terms of numerical simulations. In collaboration with NTUA, DSB, and STD, the design will be shared with the other PALAEMON partners, which will confirm and enhance the prototype by the successful compilation of the project.

A hybrid methodological design approach will be performed for the interior design of the MEV-II. The hybrid approach will be based on the inclusive design principles and will co-examine ergonomics considerations together with maritime safety regulations. As a first step, a user requirements survey will be conducted, so as to identify the specific needs of potential end-users with respect to criteria such as accessibility, ergonomics, safety, comfort, aesthetics, etc. Apart from ship passengers and crew members, special groups of end-users will be targeted, such as people with disabilities, passengers with affected cognitive/attentive/emotional factors, rescue teams, etc. Next, the determined requirements will be transformed into engineering characteristics of the MEV by exploiting the "Quality Function Deployment" (QFD) methodology. Based on the above, end-users' desires will be identified and classified, the importance of those desires will be assessed, and engineering characteristics which are relevant to those desires will be recognized. Desires and engineering characteristics will be correlated, and correlations will be verified in order to specify the design objectives and determine the priorities for the system requirements. Based on the results of the QFD methodology, the interior of the MEV will be designed in a 3D CAD design software environment. The design will be validated with the use of 3D human models and potential end-users' feedback, so as to optimize the physical human-product interaction and determine the success of the design.

3 Naval Architecture Studies

3.1 First phase. Conceptual design

The MEV-II will be studied in terms of stability, overall strength, and seakeeping. Following the requirements set in T2.2 the MEV will be unsinkable, and able to survive in rough weather. In terms of seakeeping, adequate design parameters will be considered in order to reduce the accelerations caused by waves.

The first design iterations which have been agreed upon between the WP4 partners considering the requirements set in T2.2 and the suggestions which have been put forth by the end users, show a MEV-II design depicted in Figure 1. The MEV-II vehicles will be an integral part of the ship, without the need to carry additional LBs. The design is studied to use MEV-II structures on multiple decks of the ship, in order to offer flexible mastering, but also the ability for the passengers to board the MEV-IIs in multiple decks.

The design principles, which have been taken into account during the first design phase of the MEV-II, are:

- Maximum utilization of space on the deck of the ship, while offering maximum space inside for the highest number of persons to board the MEV.
- MEV should be a part of the ship's structure, while satisfying four particular requirements, i) ease of launching and storing, and ii) the MEV IIs are easily launched and retrieved with no moving or retractable parts for the launching mechanism, iv) they are self propelled and can be used for tenders.
- The MEV-II should be unsinkable and can survive in rough weather.
- Special considerations for introducing a level of autonomy for increased safety and reliability in terms of navigation requirements and ability to operate as a swarm.

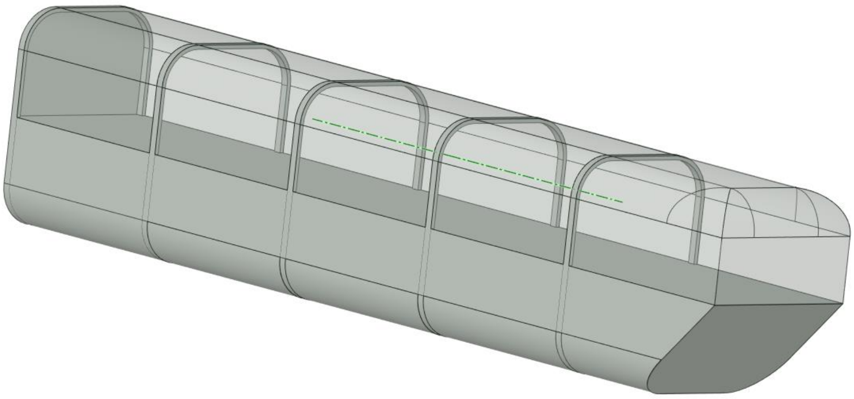

Figure 1: MEV-II design.

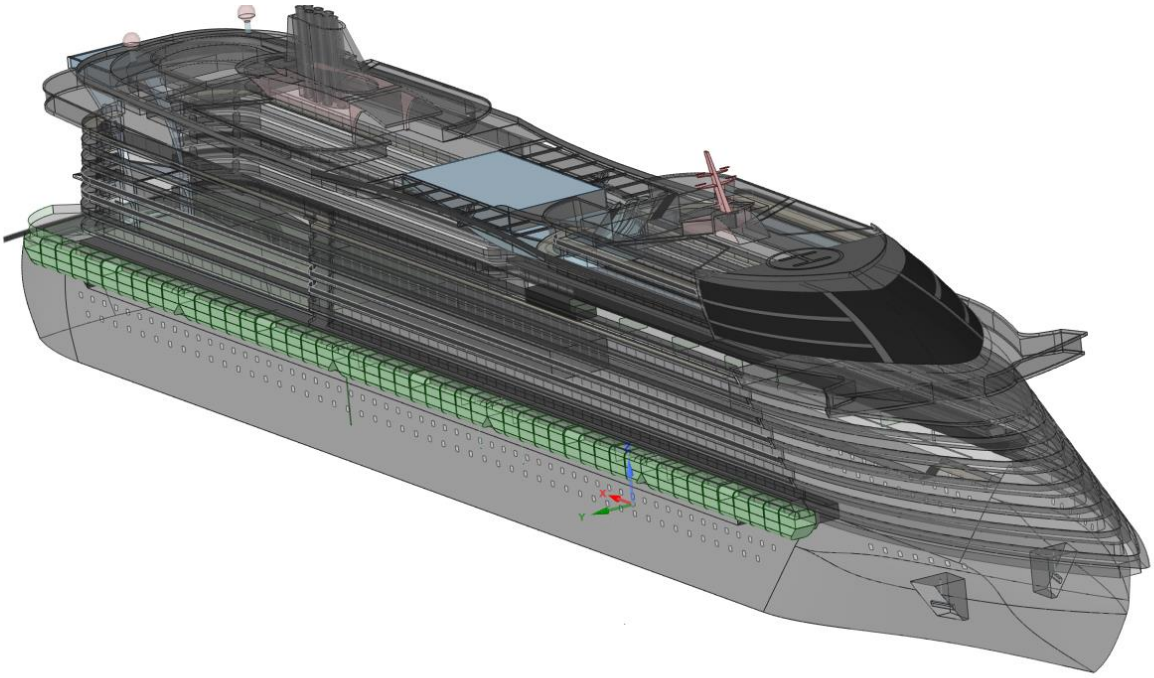

Figure 2: Initial Ship design concept for MEV II.

Cruise Ship Main Particulars

Length Overall	346.6 m
Length B.P.	334.8 m
Breadth moulded	46.24 m
Depth to main deck	19.8 m
Draught design	8.5 m
Deadweight	10000t
Main Engines	4X20500 kW
Speed Service	25 knots

3.2 MEV II design studies for a Cruise ship

The concept of MEV-II will offer increased passenger capacity for future cruise and passenger ships. In this context, a cruise ship of 6000 persons capacity has been modified extensively for the integration of the MEV-II vehicles. The MEV II-has two decks, with a capacity of 680 passengers (based on calculations for passenger space as defined by SOLAS and included at the end of this document). The calculations for passenger capacity have also taken into account the room required for the installation of the propulsion and the navigation equipment. The number of MEV-II vehicles on each side of the ship is 10, with the forward and aft MEVs used as tenders. The characteristics of the MEV-II are described in the following table. Detailed calculations about propulsion, structural design, and stability study will be accomplished in Task 4.5.

Table 3.1: MEV-II Characteristics for a cruise ship with a capacity of 6000 passengers and crew members

Decks	2
Particulars L X B X D (m)	25.3 X 7 X 5.2
Passenger Capacity	680
Inflatables	4 (2 on each side)
Number of MEV-IIs on each side of the ship	10
Minimum speed (knts)	5

Additional features will be ease of access and buffer area for satisfying the fire protection area of SOLAS.

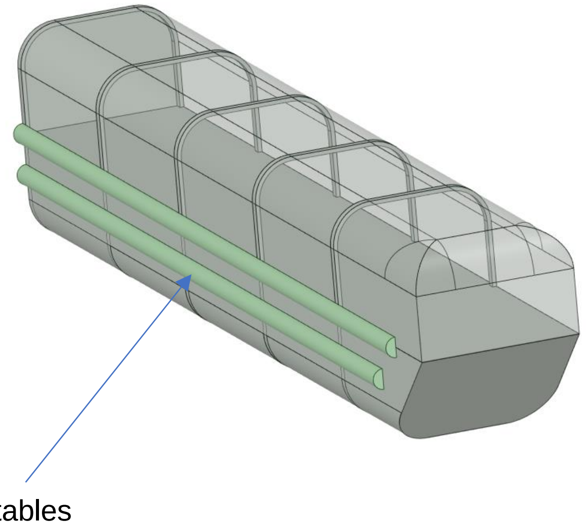

Figure 3: MEV-II concept.

3.3 Concept ship design

Cruise ships of the future, which are predicted to have a passenger carrying capacity close to 7000 crew and passengers[1,2], are envisaged to offer integrated solutions for evacuation and emergencies. The need for larger LB capacities to accommodate all passengers may antagonize the need for aesthetics – if the ship is visually appealing. Larger or more LBs may have an impact on this important requirement, even though new concepts for Mass Evacuation Vessels are indeed designed to also be aesthetically pleasing (see also CTL tender lifeboats from Palfinger Marine[3]).

The objective of MEV-II is to increase the evacuation capabilities of the vessel. The innovative concept of MEV-II aims at providing a solution to the following issues:

[1] Tsitsilonis, Konstantinos & Stefanidis, Fotios & Mavrelos, Christoforos & Gad, Andreas & Vassalos, Dracos & Timmerman, Mirjam. (2019). Concept Design Considerations for the Next Generation of Mega-Ships.

[2] https://www.cruiseindustrynews.com/cruise-news/18834-largest-cruise-companies-projecting-significant-10-year-annual-capacity-growth.html

[3] https://www.palfingermarine.com/en/boats-and-davits/life-and-rescue-boats/cruise-lifeboat-and-tenders

- Increase the LB capacity for each side of the vessel and go beyond the current SOLAS requirement.
- Reduce the time required to board the MEVs following the mustering process, and hence reduce the total time required for ship abandonment.
- Increase the level of efficiency of the MEV in terms of space.

According to the regulatory framework presented in D2.1, SOLAS Ch. III, Part B, Regulation 21 requires that the LB capacity of the side of the vessel be at least 50% of the total number of persons onboard (i.e. passengers and crew members.). Additionally, according to the same regulation, every ship should be equipped with inflatable or rigid liferafts with a capacity to accommodate at least 25% of the persons onboard for each side of the vessel. The main benefit of the MEV-II concept is that the area at each side of the ship is fully utilized to increase the total passenger capacity of LBs. In that way the ship will be able to be fitted with more LB (i.e. MEV-II) and the capacity of LB for each side of the vessel will be increased. The goal is to increase the capacity of each side to around 100% of the total number of persons onboard, therefore the total capacity of MEV-II in both sides of the vessel will accommodate around 200% of the total number of persons onboard (Figure 4).

Another innovation of the MEV-II concept is that it will be integrated into the ship's structure. A benefit of this integration is that embarkation will be conducted without the passengers and crew having to be exposed to the prevailing weather conditions on open decks. The embarkation to the MEVs will be carried out through an enclosed embarkation area/zone adjacent to the MEV. The MEV interior space will be a continuum of the embarkation deck space, enabling rapid embarkation. The embarkation zone will be subdivided according to the ship's main vertical zones and will comply with the fire protection requirements mandated by SOLAS Chapter II. Furthermore, this new design will facilitate the ship designer to locate the vessel's muster stations closer to the MEV deck.

In terms of ship design, the MEV-II concept offers the opportunity to take advantage of its external shape and integrate it with the ship's aesthetics. In particular, as shown in Figure 4, MEV-II is located on each side of the vessel and will be seen as part of the ship's structure. This will improve the overall architectural image of the ship's profile (i.e. the way that the ship looks like) and make it more attractive visually. To study this novel approach, the concept design of a 6000-passenger capacity cruise ship has undergone extensive modification by introducing a newly designed superstructure to enable the MEV-II vehicles to be seamlessly integrated into the ship structure and to serve as functional parts of the ship.

Additionally, the way that MEV-II is fitted into the ship's structure offers the advantage of easy launch and retrieval, as described in Section 4. This advantage accommodates one of the main user requirements elicited in D2.2, that the MEVs should also be used as tenders during normal operations.

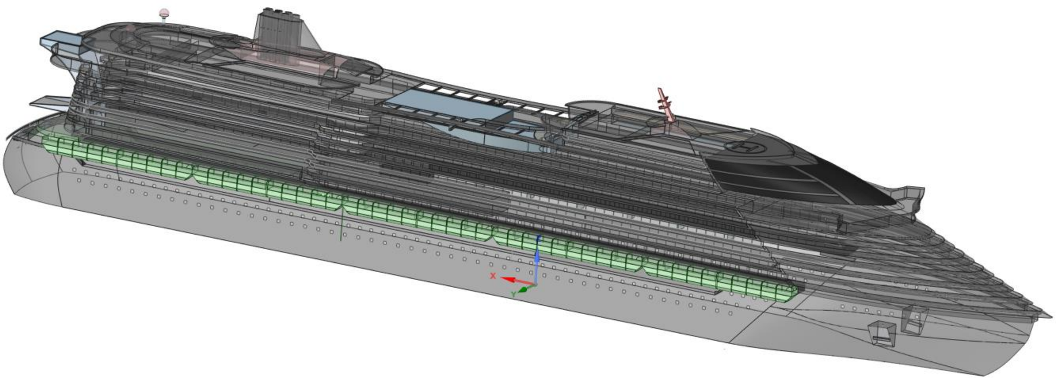

Figure 4: Cruise Ship accommodating MEV II design.

Embarkation zone for entering the MEV.

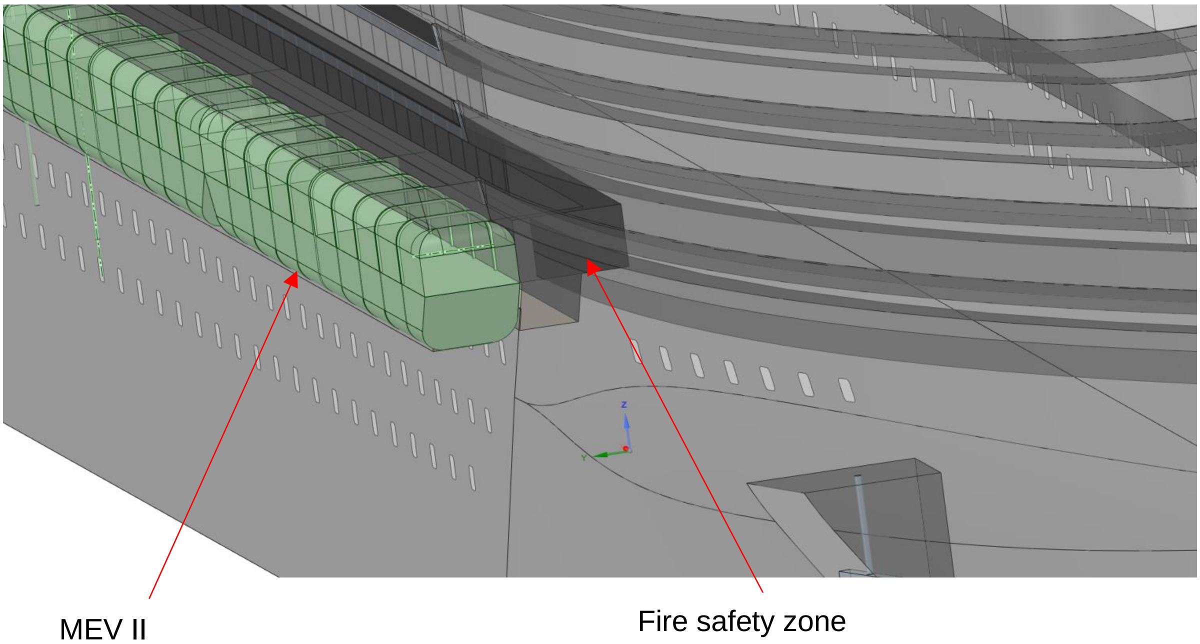

Figure 5: Integrartion of MEV-II on ship and also buffer zone for fire safety, following SOLAS.

3.4 MEV II launching

The concept of MEV-II as presented above will be equipped with an appropriate launching system. This system will be passive and operate gravitationally, without the need for external power sources or hydraulic mechanisms. The launching of MEV-II will be performed by lowering it straight down into the sea (Figure 6). The MEV-II launching mechanism will be fitted with suitable winches that will control the speed of the MEV while descending by using mechanical brakes. The mechanism will be located in the space above the MEV-II (and below the upper deck). The winches will have wires that will be hooked on the top of the MEV-II. The number of winches and the exact location of the hook points for each MEV will be identified in the second phase of the design process, based on the results of the FEA and the development of the structural design. The launching system will be operated from onboard the vessel as well as from the MEV-II.

The far fore and aft MEVs on each side (port and stbd) of the ship will be used as tender boats as well. For these MEVs, the launching system will allow the regular retrieval of the vehicle. For this reason, the mechanism will also be operated with electrical power that will enable the MEV-II tenders to be retrieved and reused during normal operation.

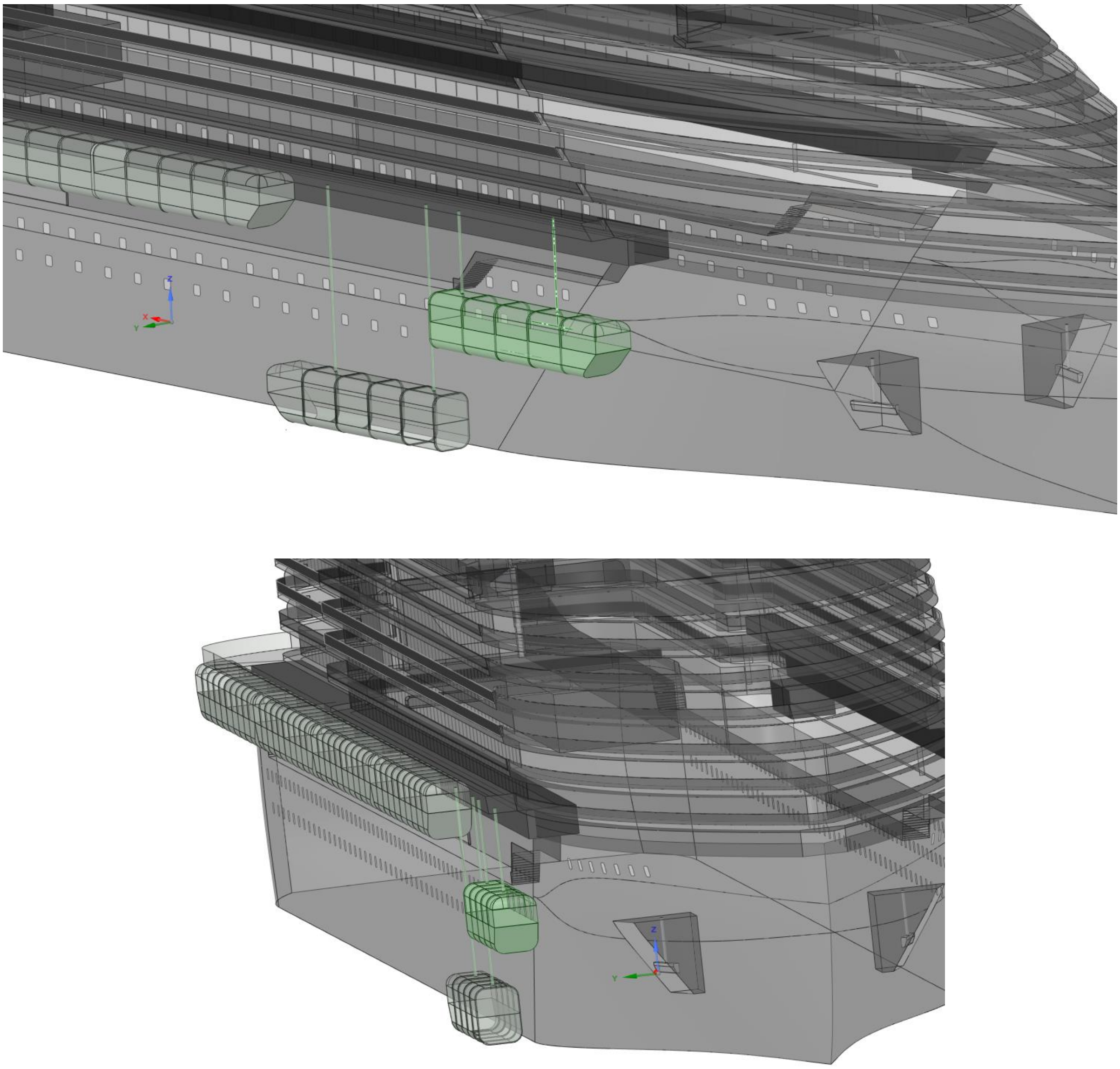

Figure 6: Launching MEVs.

4 Requirements for the MEV-II

This section contains the first version of the functional requirements, non-functional requirements as well as the constraints for the MEV-II concept, as described in the previous sections. These requirements are the result of an integration process that considered the stakeholder needs as they have been identified inTask 2.2, the state of the art in the domain, the relevant regulatory framework, and the applicable engineering principles.

The concept of MEV-II is presented and analysed following discussions with various stakehodlers (e.g. captains, Flag state authorities, shipping companies, LB designers/naval architects, etc.) to elicate and develop the final set of requirements regarding the MEV-II.

4.1 Functional requirements

Functional requirements define what functions need to be performed to accomplish the objectives (Shea, 2020). The final set of functional requirements for MEV-II is included in Deliverable 2.3 “Final version of PALAEMON Requirement Capture Framework”. Nevertheless, a first set of functional requirements (high-level functions) are presented herein by using “shall-statements” (which is a standard format for expressing requirements). Additionally, some performance requirements are provided. Performance requirements are attributes of the functional requirements (ISO/IEC/IEEE, 2018) and define how well the system needs to perform the intended functions (Shea, 2020). These performance requirements have the form of minimum requirements to be met by the vehicle and originate from the relevant regulatory framework. Thus, there is a direct link with the constraints, a type of requirement imposed by external sources, that will be addressed later in section 4.2 below.

The functional requirements for MEV-II are identical or similar to the respective requirements already identified for MEV-I in Deliverable 2.2 “PALAEMON Requirement Capture Framework”. This overlap is logical since both vehicles serve the same purpose, that is to evacuate safely passengers and crew from a cruise/passenger ship, and are subject to the same constraints imposed by the relevant rules and regulations. The fisrt set of functional requirements for MEV-II concept are presented below.

4.1.1 Seaworthiness

MEV-II shall be able to navigate away from the damaged ship and safely sail on the high seas under a variety of conditions. Thus, it shall have ample stability (intact and damaged) in a seaway to survive rough weather, and ample manoeuvrability to safely sail away from the ship and connect with other MEVs.

4.1.2 Propulsion - endurance

MEV-II shall be self-propelled by an appropriate propulsion system. The propulsion system shall enable the MEV to be operated fully loaded at 6 knots for a period of not less than 24 h.

4.1.3 Accommodation

MEV-II shall be capable of sustaining the lives of the embarked persons and providing a safe and habitable environment for people after its launching. This capability includes protection against the natural environment, provision of appropriate seating, and provision of sufficient habitability features.

4.1.4 Embarkation

MEV-II shall enable safe, easy, and rapid embarkation - disembarkation of persons regardless of their physical condition, age, and mobility, including those needing evacuation by stretcher or other means, and those needing recovery from the sea.

4.1.5 Launching

MEV-II shall be capable (structurally and operationally) of safe and fast launch (when it is fully loaded) and retrieval by an appropriate launching and retrieval system, under normal operating conditions and under adverse ship and weather conditions. Specifically, it shall enable safe launching into the water when it is fully loaded, under all conditions of trim of at least 10°, and list of at least 20° either way. The MEV shall also enable preparations for embarkation and launching to be performed by no more than two crew members and to last less than 5 min.

4.1.6 Hull structure

MEV-II shall be of sufficient strength to be safely launched into the water when it is fully loaded. The structure of the MEV shall withstand, when the MEV is fully loaded and with, if applicable, skates or fenders in position, a lateral impact against the ship's side at an impact velocity of at least 3.5 m/s and also a drop into the water from a height of at least 3 m. The structure shall also enable towing when the ship is making headway at a speed of at least 5 knots in calm water.

4.1.7 Status monitoring

MEV-II shall enable the Master and the Command Team of the ship to monitor in real-time its availability, status, and persons on-board throughout the evacuation process.

4.1.8 External communication

MEV-II shall provide a means for external communication. The external communication system shall enable communication between ship and MEV, and between MEVs. It shall also enable emergency communication with rescue centers/units.

4.1.9 Navigation

MEV-II shall provide means for safe and efficient navigation on the high seas and in adverse weather conditions.

4.1.10 Training

MEV-II shall be designed to facilitate familiarization, training, and drills for passengers and crew members.

4.1.11 Launching mechanism

The launching mechanism of MEV-II shall enable safe and efficient launching and retrieval of the vehicle both under normal operating conditions and under adverse ship and weather conditions. In particular, the launching mechanism shall enable the MEV-II to be launched against unfavourable conditions of trim of at least 10° and list of at least 20° either way: a) when boarded, as required by SOLAS Regulation III/23, by its full complement of persons; and b) with not more than the required operating crew on board. It shall also allow launching of the fully loaded MEV with and without electric power supply.

4.2 Non-functional requirements

The non-functional requirements describe the qualities of the system (ISO/IEC/IEEE, 2018). Therefore, they incorpoarate the so-called “ilities”, such as survivability, reusability, reliability, maintainability, safety, security, etc.

4.2.1 Aesthetics

MEV-II shall enable smooth integration into the ship structure to preserve the visual appeal of the ship exterior without compromise in terms of MEV’s functionality.

4.2.2 Availability

MEV-II shall be operational and accessible when required for use during emergencies. Thus, it shall have sufficient redundancy to provide for high availability.

4.2.3 Safety

MEV-II shall enable safe operation by the crew and ensure the safety of all embarked persons.

4.2.4 Robustness

MEV-II shall be resistant to rot, corrosion, seawater, oil, fungal attack, and deterioration due to sunlight.

4.2.5 Maintainability

MEV-II shall provide for easy maintenance and retention in a fully operational state.

4.3 Constraints

According to Pohl and Rupp (2015), constraint represents a requirement that limits the solution space beyond what is necessary for meeting the given functional and quality requirements. Such a requirement can constrain the system itself or the development process. Examples of constraints are national and international regulations developed by respective authorities, as well as requirements stemming from industry standards.

MEV-II represents a novel life saving craft. Nonetheless, it must be able to be incorporated into the relevant international maritime regulatory framework. The SOLAS 1974, as amended, and the LSA Code provide the primary set of regulatory requirements for life saving appliances and arrangements for cruise and passenger ships. In general, these requirements, that form part of the constraint's context, are stringent. In this perspective, the design and introduction of an innovative vessel such as MEV-II is a difficult and challenging task. Still, SOLAS provisions provide some flexibility and enable alternative lifeboat and evacuation vessel designs to be permitted as long as they provide equivalent safety standards and they are approved by the Administrations (Flag States). An example of such deviation is the introduction of mega-lifeboats (with a very large capacity, up to 450 persons so far) into the cruise industry.

SOLAS (Regulation III/38) specifies the approval process to be followed when an alternative design deviates from the relevant prescriptive requirements. An engineering analysis of the design must be carried out, and then submitted to the Administration for evaluation and approval. The analysis can be based on the relevant guidelines provided by IMO (2006). The engineering analysis must include, as a minimum, the following elements:

- identification of the prescriptive requirement(s) with which the life-saving appliance and arrangements will not comply;
- identification of the reason the proposed design will not meet the prescriptive requirements supported by compliance with other recognized engineering or industry standards;
- determination of the performance criteria for the ship and the life-saving appliance and arrangements concerned addressed by the relevant prescriptive requirement(s):
    - performance criteria shall provide a level of safety not inferior to the relevant prescriptive requirements contained in part B; and
    - performance criteria shall be quantifiable and measurable;
- detailed description of the alternative design and arrangements, including a list of the assumptions used in the design and any proposed operational restrictions or conditions;

- technical justification demonstrating that the alternative design and arrangements meet the safety performance criteria; and
- risk assessment based on identification of the potential faults and hazards associated with the proposal.

As indicated previously, an evacuation system design mainly falls under the scope of SOLAS and LSA Code. Chapter III (Life-saving appliances and arrangements), but also several references for safety requirements in Chapter II-1 (Construction – Structure, Subdivision and Stability, Machinery and Electrical Installation) and Chapter II-2 (Construction – Fire Protection, Fire Detection and Fire Extinction) of SOLAS, establish constraints for the design of MEV-II. LSA Code, as an international standard for life-saving appliances required by SOLAS, also indicates binding requirements to be observed during the project. But, given the novelty of the MEV-II concept and its unique features as a marine vehicle that go beyond the typical features of lifeboats, the SOLAS requirements regarding the passenger ship itself should be studied thoroughly and considered for the design of the MEV.

Requirements for the MEV II and systems

For MEV II, requisite systems should be present for operation, safety, navigation and tracking of the vehicle. Furthermore, it is envisaged that MEV-II could have the potential of containing a level of autonomy and the capcity to operate as swarms. This is to offer more realiable tracking, the capacity to track real time the MEVs and the to guarantee that MEVs will not stray from the pack and get lost. Systems as listed below are esential

- Navigation systems should be present and operational in the MEV.
- GPS for positioning and tracking of the MEV.
- An auxiliary system in the MEV or in the entrance for counting and even identifying the people that are situated in the MEV.
- Propulsion need for the demo MEV, MEV II design for 680 persons.
- Introduction of autonomy and AI and swarm algorithms in the vehicle operation.
- Inflatables on the sides for avoidance of hitting the ship when listed.
- Protective polymeric pads on the sides for sliding on the side of the ship when listed.
- Range of the MEV II.
- to be integrated smoothly in the ship design (aesthetics).
- compact launching mechanism (i.e. located above MEV-II).

From SOLAS and description which is also included in D4.1 the calcualtions for the minimum available passenger room is described below.

- Adequate height for the passengers and places.

The requirements for passenger accommodation in life boats, following IMO’s suggestions, dictate a minimum passenger weight of 75 kgr, while the sitting arrangement is illustrated in Figure 7. The sitting arrangment will be assessed in light of provisions which should be taken for taking on passengers with limited mobility, oiverweight, etc.

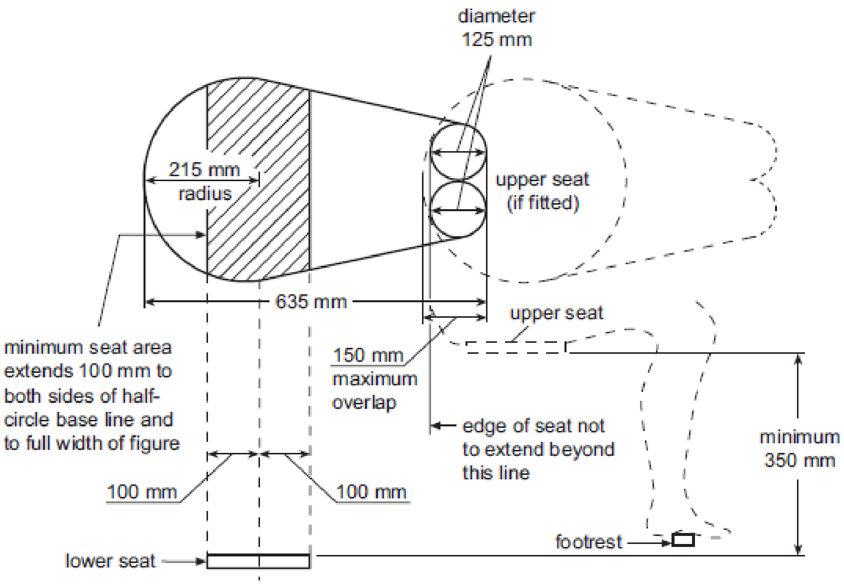

Figure 7: Seating arrangement for lifeboats[4].

5 Structural Design

MEV-II has depicted in Figure 1 has been assessed in terms of design and structural integrity, to accommodate 680 persons and neccessary power plant and engine equipment. In this sense the following analysis has been performed.

5.1 MEV II manufacturing

The MEV II is manufacture using preperg CFRP (Carbon Fiber Reinforced Composites). The possibility of using bio-composites was investigated but the structural strength of the bio-composites was not adequate enough for the weights and structural integrity of MEV-II.

5.2 MEV II structural drawings

MEV-II particulars are indicted in Table 3.1. The structural drawing is depicted in Figure 8. The vehicle has two decks, accommodating approximately 310 passengers on the bottom deck and 372 on the upper deck.

[4] https://rules.dnvgl.com/docs/pdf/gl/maritimerules2016Jan/gl_i-3-4_e.pdf

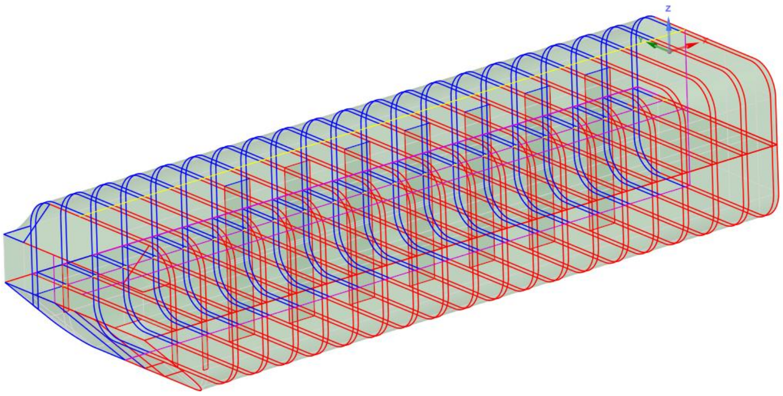

Figure 8: MEV II structural drawing.

The seating arangment for the 680 people is indicated in Figure 9, where seating is illustrated only on the one half of the ship, while the other half is identical due to symmetry.

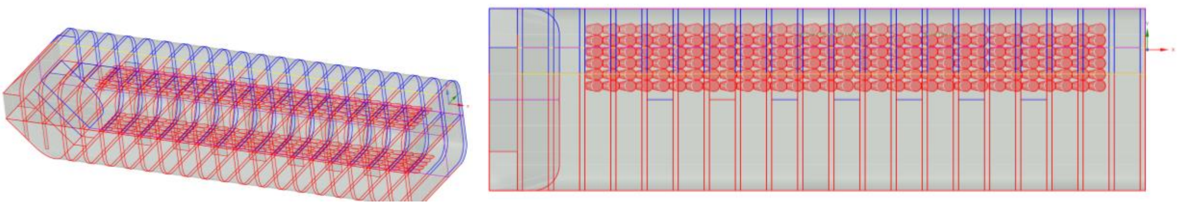

Figure 9: Seating arrangement, (only half is shown due to symmetry from CL).

5.3 MEV-II CFRP composite design

The CFRP composite building parts are illustratred in this section, depicting the number and orientation of layers and honeycomb core in the sandwich structures:

Outer skin (Figure 10).

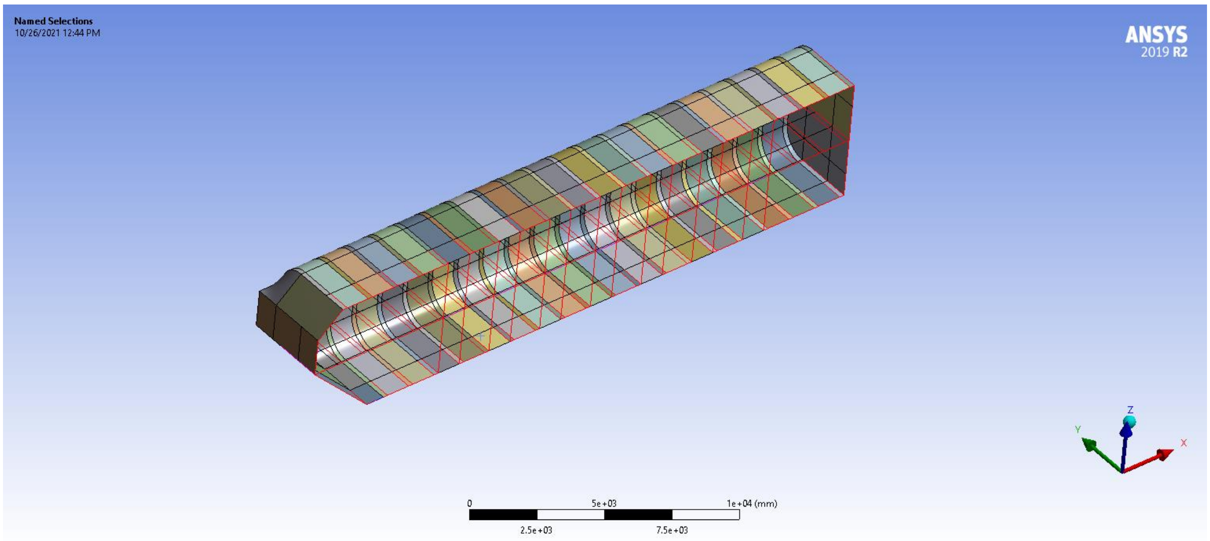

Figure 10: Outer skin.

12 layers +- 45 degrees, 40mm honeycomb core, with respect to the Local Coordinate system, with plane (1,2) tangential to the walls.

Stacking sequence	*Orientation*
6 layers CFRP prepreg	+-45
Honeycomb	40mm
6 layers CFRP prepreg	+-45

Transverse stiffeners

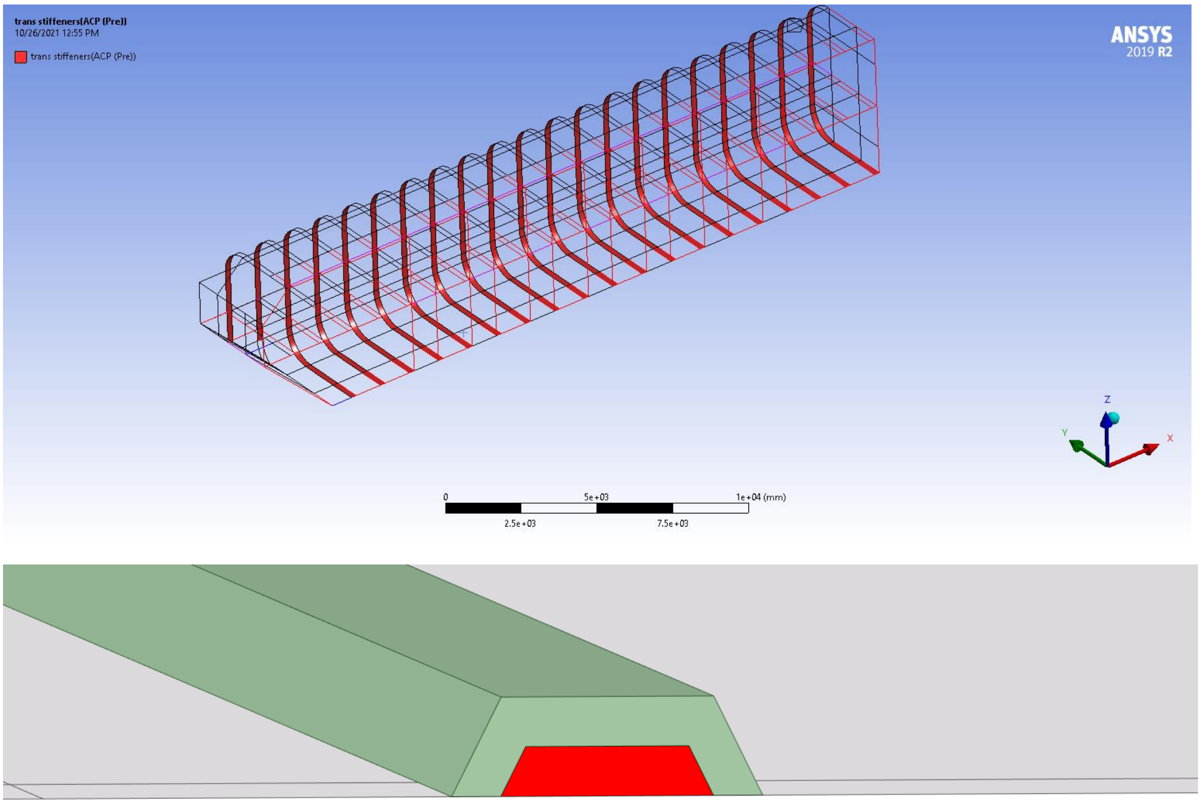

Figure 11: Above: transeverse stiffeners on MEV II, below: Transverse stiffener section; red Honeycomb core, Green composite.

16 layers +- 45 degrees, 40mm honeycomb core, with respect to the Local Coordinate system, with direction 1 parallel to the longitudinal direction of the stiffener.

Stacking sequence	*Orientation*

8 layers CFRP prepreg	+-45
Honeycomb	40mm

Floor and middle walls

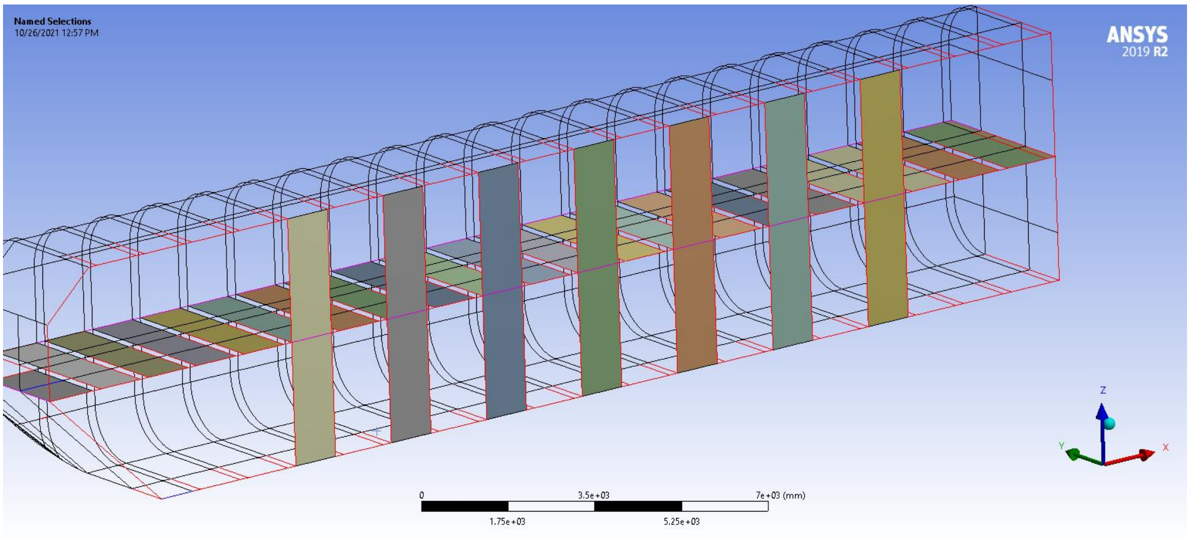

Figure 12: The floor (second deck) and middle walls on MEV-II.

12 layers +- 45 degrees, 40mm honeycomb core, with respect to the Local Coordinate system, with plane (1,2) tangential to floor and middle walls.

Stacking sequence	*Orientation*
6 layers CFRP prepreg	+-45
Honeycomb	40mm
6 layers CFRP prepreg	+-45

Longitudinal stiffeners

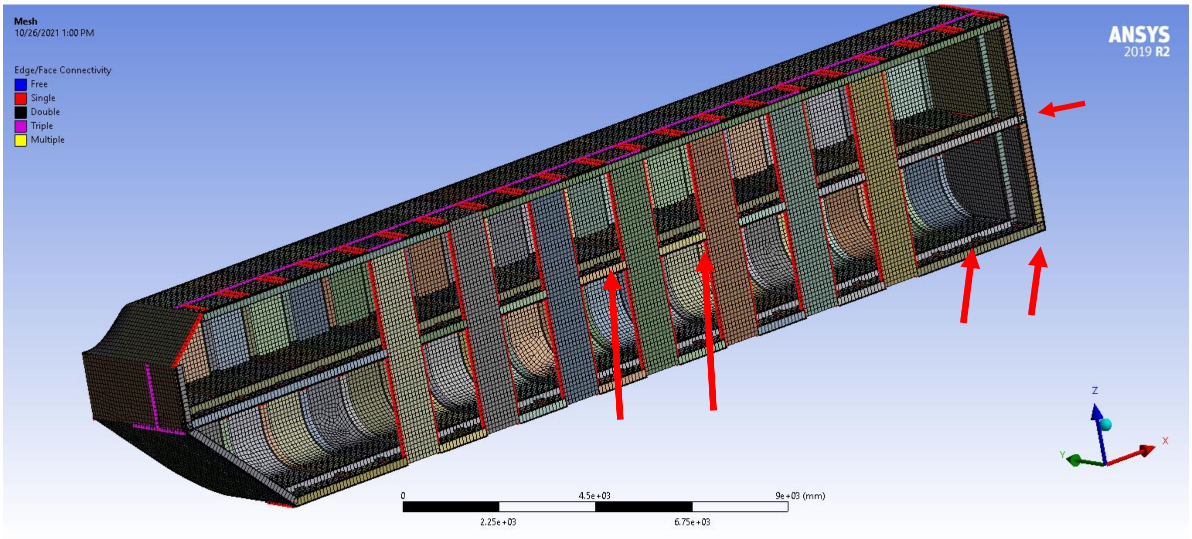

Figure 13: Longitudinal stiffeners (indicated with red arrows).

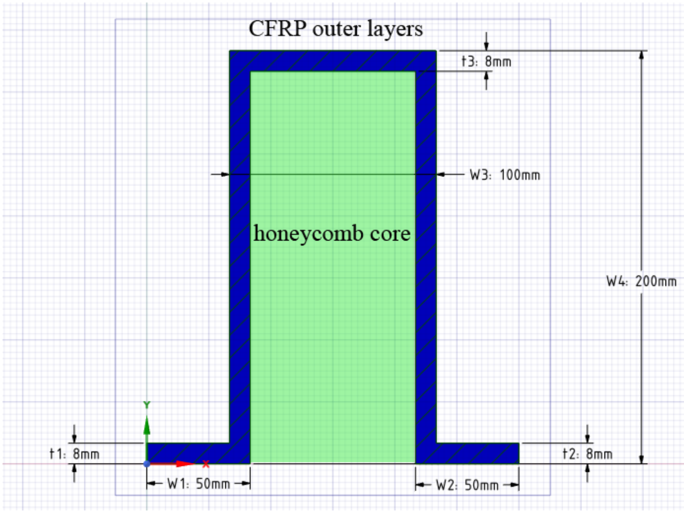

Figure 14 cross section of longitudinal stiffeners.

16 layers +- 45 degrees, 40mm honeycomb core, with respect to the Local Coordinate system, with direction 1 parallel to the longitudinal direction of the stiffener.

Stacking sequence	*Orientation*
8 layers CFRP prepreg	+-45
Honeycomb	40mm

5.4 CFRP material properties

The material properties for the CFRP and honeycomb core are depicted below:

TABLE 5.1: Epoxy Carbon Woven (230 GPa) Prepreg > Density.

Density tonne mm^-3

1.42e-009

TABLE 5.2: Epoxy Carbon Woven (230 GPa) Prepreg > Orthotropic Elasticity.

Young's Modulus X direction MPa	Young's Modulus Y direction MPa	Young's Modulus Z direction MPa	Poisson's Ratio XY	Poisson's Ratio YZ	Poisson's Ratio XZ	Shear Modulus XY MPa	Shear Modulus YZ MPa	Shear Modulus XZ MPa
61340	61340	6900	4.e-002	0.3	0.3	3300	2700	2700

TABLE 5.3: Epoxy Carbon Woven (230 GPa) Prepreg > Orthotropic Strain Limits.

Tensile X direction	Tensile Y direction	Tensile Z direction	Compressive X direction	Compressive Y direction	Compressive Z direction	Shear XY	Shear YZ	Shear XZ
1.26e-002	1.26e-002	8.e-003	-1.02e-002	-1.02e-002	-1.2e-002	2.2e-002	1.9e-002	1.9e-002

TABLE 5.4: Epoxy Carbon Woven (230 GPa) Prepreg > Orthotropic Stress Limits.

Tensile X direction MPa	Tensile Y direction MPa	Tensile Z direction MPa	Compressive X direction MPa	Compressive Y direction MPa	Compressive Z direction MPa	Shear XY MPa	Shear YZ MPa	Shear XZ MPa
805	805	50	-509	-509	-170	125	65	65

TABLE 5.5: Epoxy Carbon Woven (230 GPa) Prepreg > Orthotropic Secant Coefficient of Thermal Expansion.

Coefficient of Thermal Expansion X direction C^-1	Coefficient of Thermal Expansion Y direction C^-1	Coefficient of Thermal Expansion Z direction C^-1
2.2e-006	2.2e-006	1.e-005
Zero-Thermal-Strain Reference Temperature C		
20		

TABLE 5.6: Epoxy Carbon Woven (230 GPa) Prepreg > Tsai-Wu Constants.

Temperature C	Coupling Coefficient XY	Coupling Coefficient YZ	Coupling Coefficient XZ
	-1	-1	-1

TABLE 5.7: Honeycomb > Density.

Density tonne mm^-3
8.e-011

TABLE 5.8: Honeycomb > Orthotropic Elasticity.

Young's Modulus X direction MPa	Young's Modulus Y direction MPa	Young's Modulus Z direction MPa	Poisson's Ratio XY	Poisson's Ratio YZ	Poisson's Ratio XZ	Shear Modulus XY MPa	Shear Modulus YZ MPa	Shear Modulus XZ MPa
1	1	255	0.49	1.e-003	1.e-003	1.e-006	37	70

TABLE 5.9: Honeycomb > Orthotropic Stress Limits.

Tensile X direction MPa	Tensile Y direction MPa	Tensile Z direction MPa	Compressive X direction MPa	Compressive Y direction MPa	Compressive Z direction MPa	Shear XY MPa	Shear YZ MPa	Shear XZ MPa
0	0	5.31	0	0	-5.31	0	1.21	2.24

5.5 MEV-II design and analysis

MEV-II weight groups have been evaluated and dictated below:

a) Weight of structure 34.5 tns
b) Weight of 682 passengers (70 tns)
c) Weight (front section) of navigation equipment = 500 kgr
d) Weight of engine = 1 tn

FEM analysis on the MEV structure, considering CFRP material with material properties illustrated in previous section. The analysis is linear elastic, using shell elements for outer wall, floor and middle walls and beam elements for transverse and longitudinal stifenners. Special shell elements are chosen that incorporate mluti layer material properties for the CFRP composite. Lastly only the half of the MEV-II structure is modelled due to symmetry (geometry and boundary conditions). Symmetry is on the CL of the vessel (Figure 15).

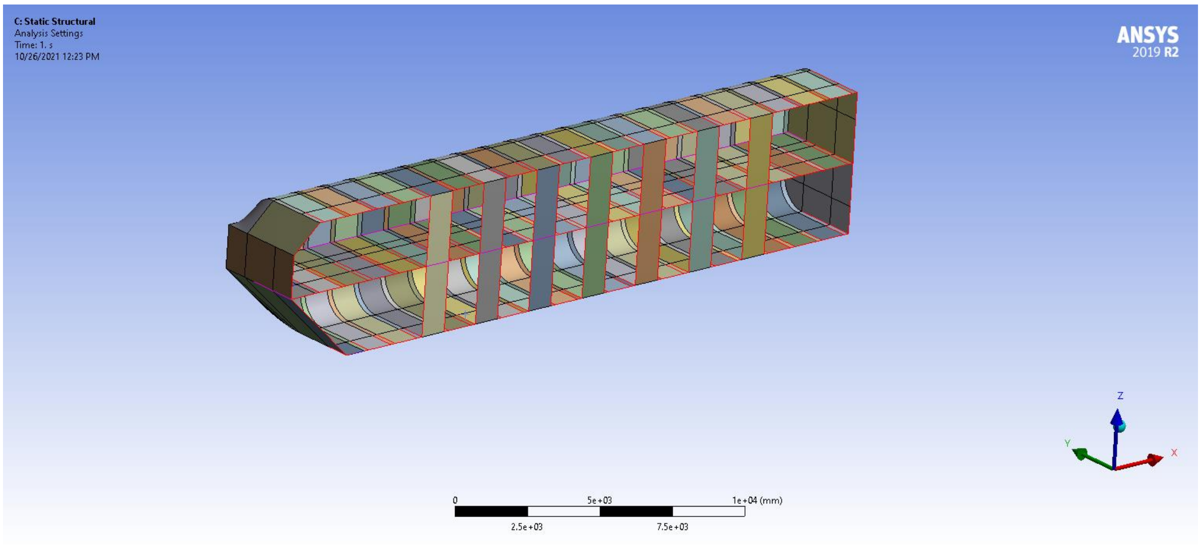

Figure 15: Half the structure is modelled (on CL) due to symmetry.

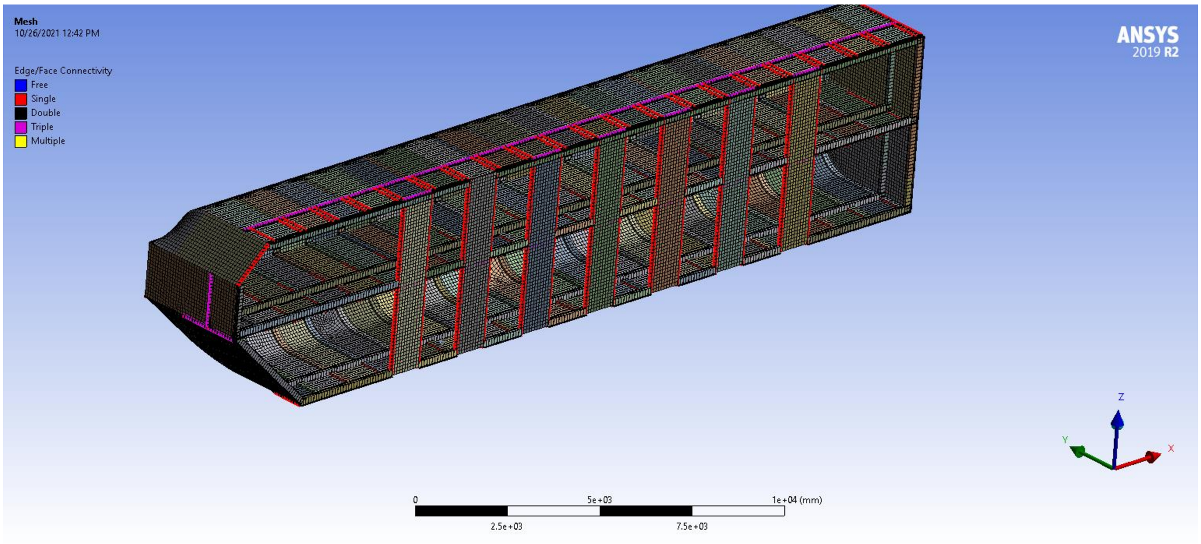

Figure 16: MEV-II model messed.

Two load cases were selected:

a) MEV-II is in saging condition, while its supported from two crests of waves at aft and fore locations.
b) Fixed supports on the top of MEV-II to simulate the launching of the MEV with full weight.

Analysis results:

<u>Fixed supports on fore and aft end of MEV (being supported by two waves fore and aft)</u>

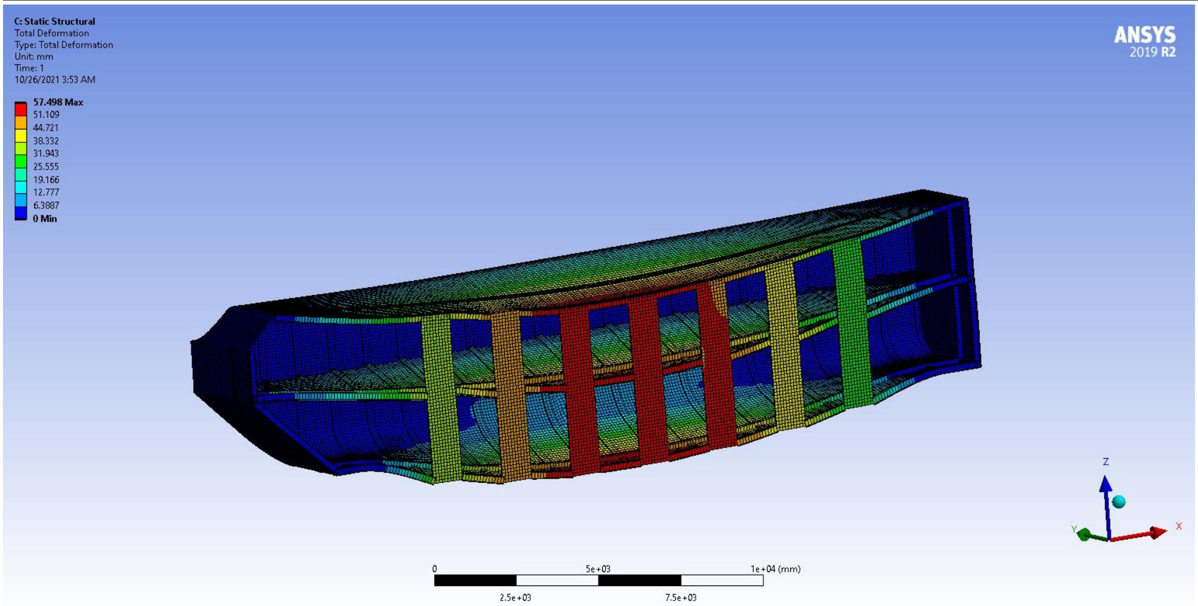

Figure 17: Total Deformation (mm).

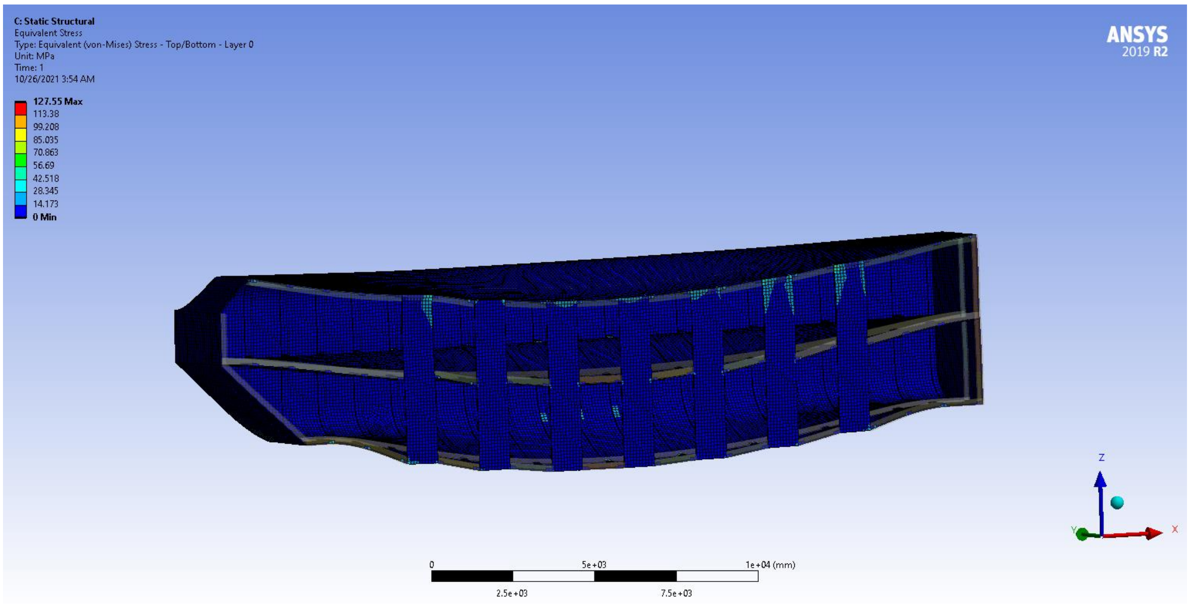

Figure 18: Equivalent Stress. Maximum 127 MPa in stress concentration areas.

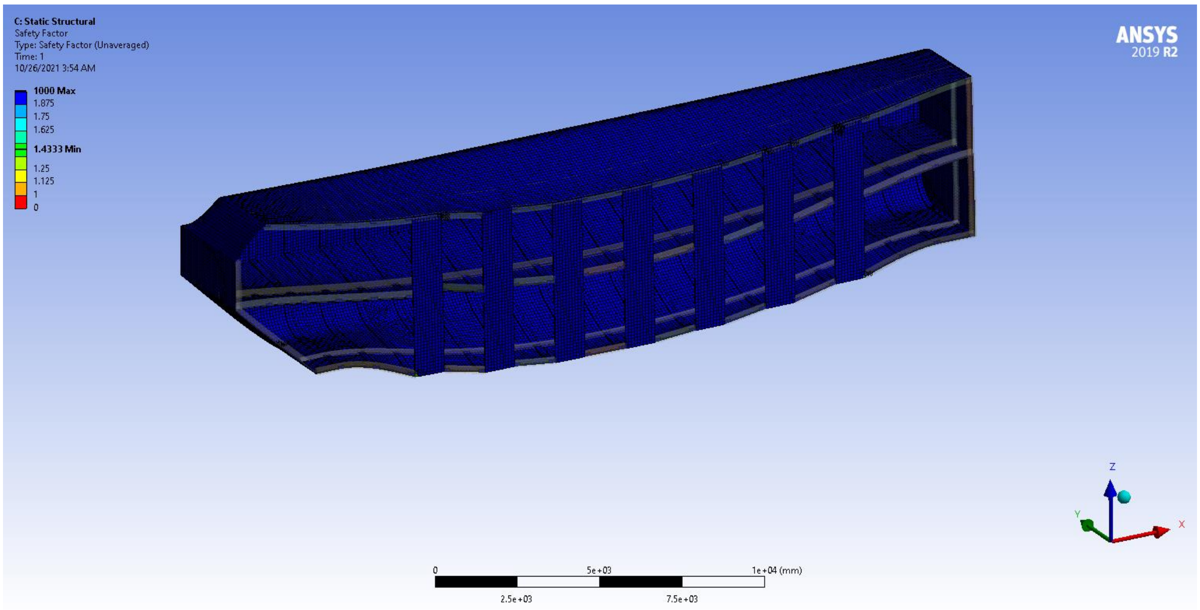

Figure 19: Safety factor on structure, minimum 1.43 on stress concentration areas.

<u>Fixed supports on top (being supported by launching ropes)</u>

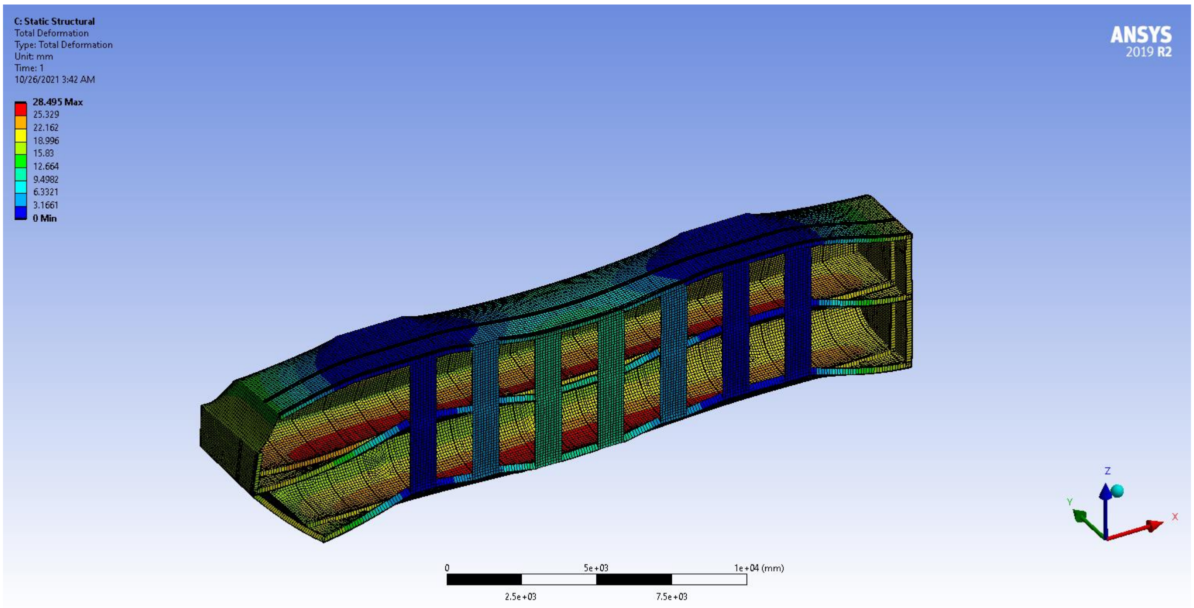

Figure 20: Total Deformation (mm).

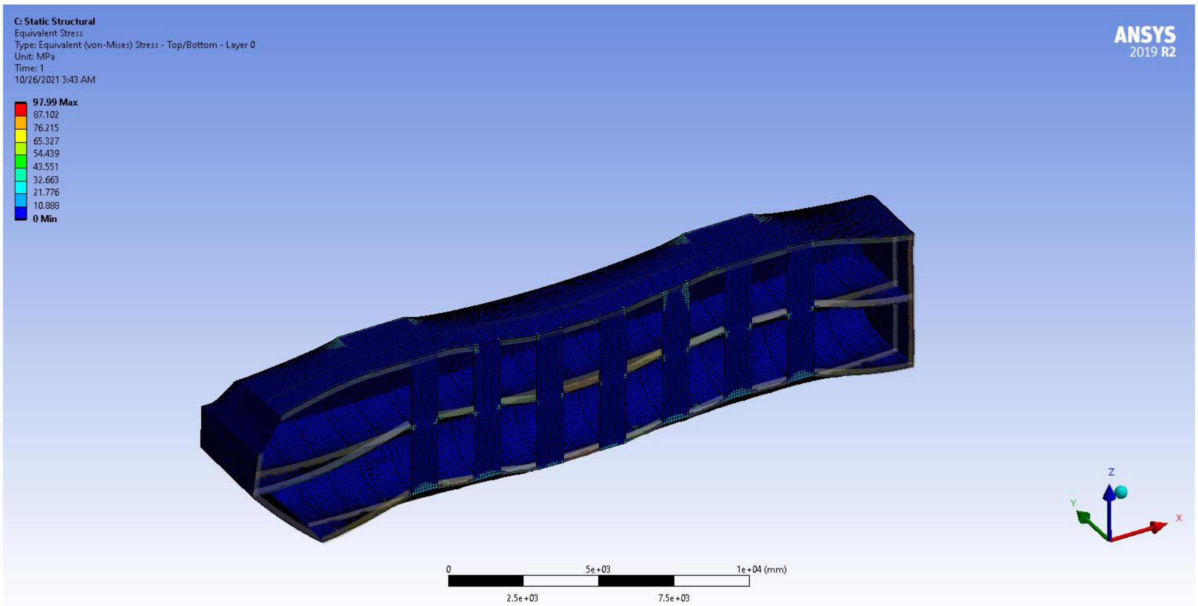

Figure 21: Equivalent Stress. Maximum 98 MPa on stress concentration areas.

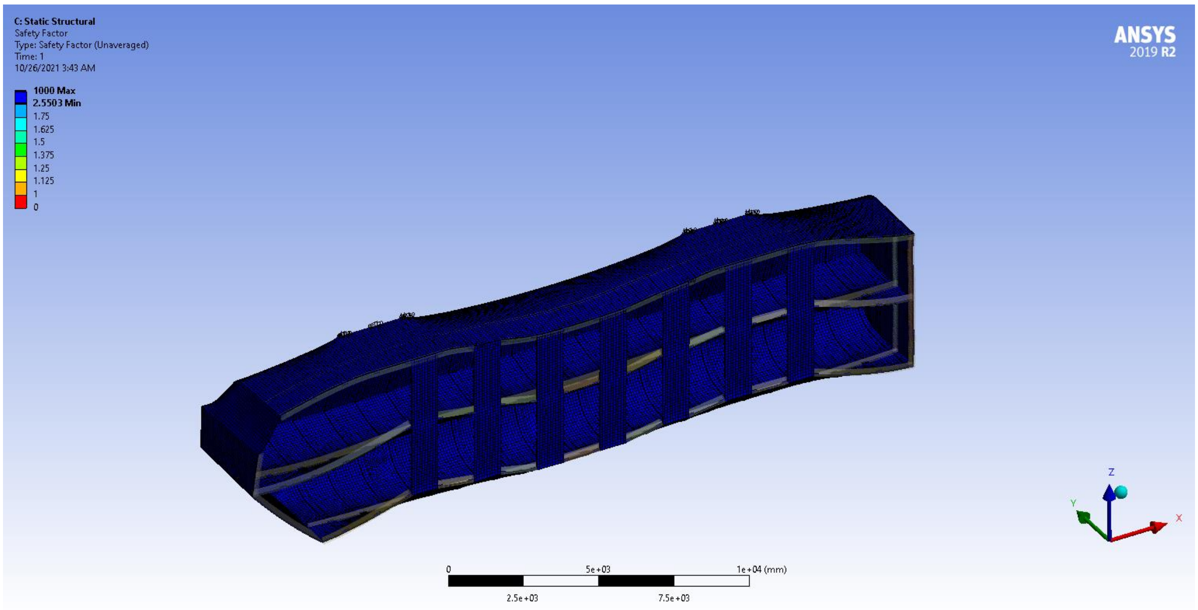

Figure 22: Safety factor on structure, minimum 2.55 on stress concentration areas.

5.6 Discussion

Both loading conditions, which were selected as being the most severe for the vessel but also MEV-II representative loading conditions (launching and fully loaded). The current design and selection of material properties, shows that the MEV-II can withstand all loads and the structural integrity is well above failure limits, exhibiting SF of 1.43 and 2.55 for the two loading cases, respectively. It should also be indicated that these SFs are in stress concentration areas which can show increased stresses. In Figures 19 and 22 it is observed that the whole structure is 1.875 (first loading case) and 2.55 (second loading case), respectively. In this manner MEV-II structural design using CFRP and honeycomb core for the sandwich structures exhibites a structural response which is well within acceptable safety margins.

In D4.5 the following aspects of the MEV I concept will be assessed:

- Stability
- MEV II GA
- GA and access points from Cruise ship decks,
- Structural analysis of launching system

6 Conclusions

A 6000 passenger Cruise ship design has been heavily modified to accommodate the new MEV-II designs. These will be operational as recreational areas when in normal operation and used as LBs when in evacuation, after an accident. The MEV-II have been designed for capacity of 605 pesrons. This will offer a 100% passenger capacity for the MEVs on each side of the ship. The detailed designs for propulsion, strength and stability will be accomplished in Task 4.5 and included in the relevant deliverable.

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