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Design of A Self-Levelling Platform for Medium and Large-Sized Yachts

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Abstract
In the boating accessories field for medium and large-sized yachts, the possibility of installing mobile platforms is becoming of increasing interest. These components could allow the ship owner to have a wide free area for different uses. The application as a helideck for helicopter landing and parking is certainly the most interesting and critical one from a mechanical viewpoint. No references about the design criteria of mobile platforms are available in either the technical literature or the international standards. An innovative mechanical system has therefore been proposed, with advanced mixed technical solutions for both the platform structure and the self-levelling system. The aim of this paper is to report the constructional technical solutions adopted during the design of a mobile multi-purpose and self-levelling platform to be installed on boats 30 (or more) meters long.
Keywords: structural design, mobile platform, marine environment, Ti-6Al-4V, FEM, modelling helideck.

I. INTRODUCTION

In the last years, the boat accessories industry has shown an increasingly driven search for new, technologically advanced products. The medium-large sized market has recently shown its interest for the opportunity to install mobile multi-purpose platforms, which could be used as landing and parking surface for helicopters, on boats from 30 meters in length on. This application proves to be particularly interesting and, although the possibility of helicopter landing spots has been expected in recent concept-design yacht studies, a commercial product which can fulfill this requirement does not exist today. From the structural point of view, the utilization of the platform in question as a landing and parking surface for helicopters is surely the most demanding condition, and for this reason this application was used as a benchmark for the design, the sizing and the verification of the structural components. Helicopter landing platforms have long been installed on marine structures such as offshore platforms and large military, merchant and tanker ships. The questioned platforms are however fixed structures, without any substantial limitation on mass and dimensions. The mechanical system presented in this study, on the contrary, must be a folding structure, so that it can be accommodated under the deck, in the prow or stern region, and it must not interfere with the ship design and its stability during the navigation. For these reasons, during the development of the platform, particular care has been taken in the determination of its mass and dimensions in the folded configuration, with the purpose to reduce them to the minimum. Considering the current standards, guidelines for the design of fixed helicopter landing platforms are available in the documentation, in order to define the operating conditions, the applied loads and the operational limits which have to be considered in the developing phase of the project [1-8]. These standards are however typical of the design of fixed platforms, and references to moving (and folding) mobile platform, with attitude control systems of the landing surface, are missing. The reported standards have then been used to define, with preventive assumptions, the operating conditions, the applied loads, and the possible operating limits. The most critical components, which are presented in this paper, are the folding mobile structures, the main framework of the platform and the landing surface covering. Considering the requirements in terms of lightness of the whole structure, the design has involved the choice of different light weight alloys, as well as composite materials. For every analyzed component, both the theoretical approach, by the analytical determination of the load conditions and by the use of dimensioning and verification formulas from the classical machine design, and the numerical approach through the finite element analysis have been used. It has been necessary to develop three-dimensional FEM models of the entire structure and of some specific components. Appropriate infinite lifetime fatigue verifications have been performed on components which were considered to be subject to dynamic loads. In this paper, the technical solutions developed in the context of the project commissioned by Besenzoni S.p.A. company – Sarnico (BG) – to the GITT (Centre on Innovation Management and Technology Transfer of the University of Bergamo) are presented. The platform in question has been presented at the Genoa Boat Show, held in October 2010. Figure 1 shows the mobile platform mounting at the Besenzoni's stand at the 50th Genoa Boat Show.

Figure 1. Platform mounting at the 50th Genoa Boat Show 2010.

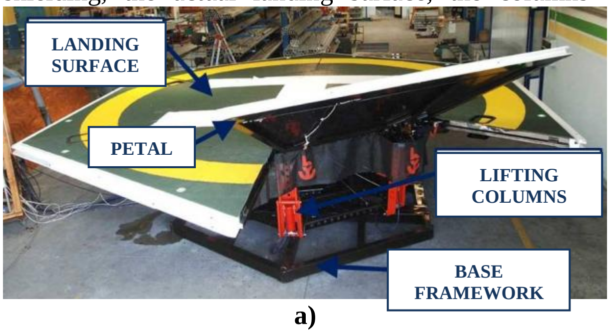
II. ILLUSTRATION OF THE FRAMEWORK AND OF THE OPERATING CONDITIONS

In this section the platform description in terms of its main components is reported, and its movimentation is briefly presented. The operating conditions of the device are also presented, with particular care for which regards the applied loads and the adopted reference standards. The platform in question has been designed to be installed on the prow or the stern of a medium or large-sized yacht (length starting from 30 m), and its framework must be such as to be folded and closed in order to be stored in a specific housing under the deck. Figure 2 shows an example of the lifting and opening sequence of the platform, installed on the prow of a large-sized yacht.

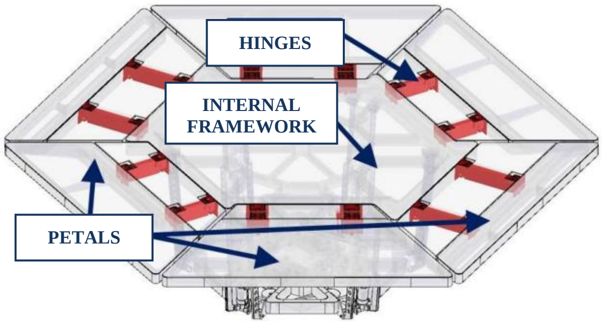
Figure 2. Platform installation example, showing the lifting and opening sequence.

2.1. Illustration of the platform

As depicted in Figure 3(a), the platform presented in this study is composed by different units: the upper framework which forms, along with its shielding, the actual landing surface, the columns which allow the support and the lifting of the first, and the base framework, which permits to constrain the whole structure and consents to level the landing surface as a function of the boat oscillation due to the wave motion.



a)



b)

Figure 3. Platform pictures with the indication of the main components.

Regarding the support columns, they are composed by two hinged halves; a hydraulic actuator is housed in the lower half of each column, thus allowing the opening of the columns and the lifting of the upper framework. The components of the upper framework are pointed out in Figure 3(b); particularly highlighted are the central framework, which is supported by the columns and forms the central part of the landing surface, the petals, which can be folded on the central framework in order to allow the housing of the structure in an appropriate casing under the deck, and the connecting hinges between the petals and the framework. The central framework and the petals are finally covered by appropriate panels, which will be carefully described afterwards.

2.2. Loads analysis

The dimensioning of the structure has been carried out considering its use as a helicopter landing and parking platform. In order to determinate the extent of the loads to be applied on the structure, the standards which regarded, even in a partial way, the design of landing platforms for boats and off-shore structures, have been considered. The main standard in this sense is the CAP 437 standard, issued by the British *Civil Aviation Authority* [3], which defines the loading conditions under normal operations and in case of emergency landing, depending on the expected helicopter model. In addition to the aforementioned standard, specific standards for the definition of the effects induced by the ship movements due to the wave motion and to the wind influence have been taken into account. Dynamic loads have been evaluated according to RINA standards [6], and considering the American oil industry standard (*American Petroleum Institute*) [7], used to estimate the forces caused by the wind action. The helicopter class which is expected to land on the platform can be represented by the Eurocopter – Colibrì EC120B model, depicted in Figure 4, the characteristics of which are listed in Table 1.

Following the CAP 437 standard, the platform must be designed in order to resist at every interaction force with the helicopter, given, in the worst case, by the landing in emergency conditions, by the weight of the platform, by a possible distributed load due to the stationing of people or of other elements on the landing surface, by atmospheric events and by wave motion. By applying precautionary considerations, the standard determines to apply the resultant of these loads as a concentrated force in a point of the platform framework. As regards the emergency load, it is expected that it should have both a vertical component and a transversal component. The vertical load is given by the helicopter maximum take-off mass (MTOM) [1], as reported in Table 1, amplified by a 2.5 coefficient, in order to account for the dynamic effects, and by a further 1.3 factor, which accounts for the structural response. The transverse load is considered in order to prevent for a not perfect helicopter landing, and is proportional to the take-off mass, diminished by a factor of 0.5. Eventually, as regards the distributed load, the standard prescribes to consider a value of 0.5 kN/m^2. Following the API standard [7], the active load due to the wind, which is a function of the wind velocity, the exposed surface and the relative positioning between the framework and the helicopter with respect to the boat and the free surface of the sea, can be decomposed in a transverse punctual force, which has to be added to the lateral punctual landing loads determined previously, and in a transverse force exerted on the platform, which must be distributed on one of its sides.

To evaluate the loads due to the wind, the following environmental conditions have been considered:

- Platform height (z) above sea level: z = 10 m.
- Characteristic gust time: t = 1s.
- Platform area (A) interested by the wind action: A = 32 m^2.
- Wind reference velocity: U_0 = 36 m/s.
- Wind gust velocity: u = 54 m/s.

The wind speed values are strictly dependant on the operating conditions, and in order to contemplate the widest range of possible circumstances, the choice has been made by taking values which were in favour of safety.

Figure 4. Eurocopter-Colibrì EC120B.

Table 1. Eurocopter EC120B helicopter charactheristics

Total length, rotor included:	11.52 m
Main rotor diameter	10.00 m
Maximum height	3.40 m
Fuselage width	1.50 m
Fuselage length	9.60 m
Take-off mass (MTOM)	1800 kg

Table 2 sums up the loads generated by an emergency landing, relative to the Eurocopter – Colibrì EC120B, as they have been used for the dimensioning and the static verification of all the platform components.

Table 2. Summary of static loads used for the dimensioning and the verification analyses on the platform.

Load types	*Standard Reference*	*Cause*	*Direction*	*Value*
Punctual	CAP 437	Emergency landing	vertical	55.0 kN
		Emergency landing	horizontal	8.4 kN
	API RP 2A-WSD	Wind	horizontal	5.0 kN
Distributed	CAP 437	Structural weight	vertical	about 20 kN
		Snow, personnel	vertical	0.5 kN/m^2
	API RP 2A-WSD	Wind	horizontal	1.0 kN

The dynamic loads induced by the wave motions have been used for the fatigue verification of the components which were subject to cyclic loads. Wave motion, which affects the boat in open water, produces inertial actions on the self-levelling platform, caused either by the proper structural weight, as well as the effect induced by the mass of the helicopter stationing on the platform. These dynamic loads have been determined in accordance with the RINA technical standard [6].

Table 3. Helicopter Centre of Gravity coordinates

X-axis coordinate	x	35 m
Y-axis coordinate	y	3 m
Z-axis coordinate	z	10 m

Table 4. Main boat dimensions

Boat length	L	40 m
Boat width	B	8 m
Draft	T	3 m
Waterline height	T_1	3 m

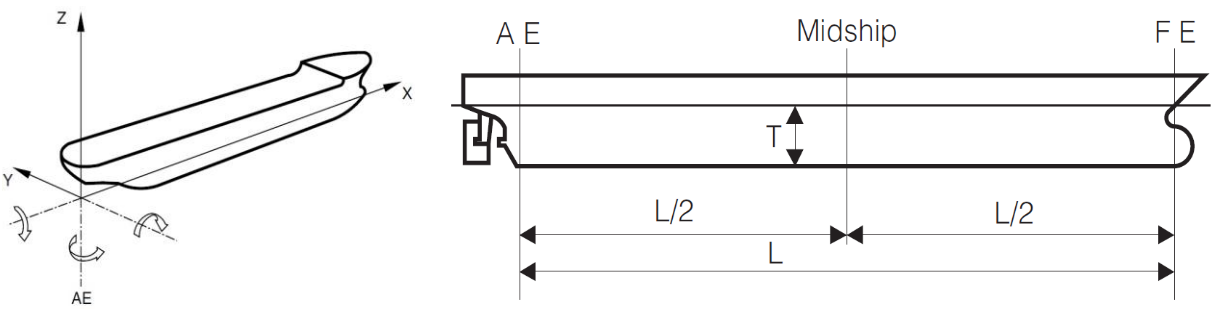


Figure 5. Reference system and indication of the main boat dimensions.

Being known the average dimensions of a possible yacht for the platform installation, and the helicopter positioning with respect to the boat, acceleration values have been obtained, hence determining the inertial forces acting on the platform itself. By referring to Figure 5, the main boat dimensions and the helicopter centre of gravity position have been reported, respectively in Table 3 and Table 4. The values of the dynamic loads acting on the platform in the horizontal and transverse direction have been then calculated as a function of the evaluated accelerations, in order to perform the infinite fatigue life verification. The forces values have been determined in different wave motion conditions, with precautionary considerations, and they have been applied punctually on the platform framework. Table 5 sums up the dynamic loads acting on the platform, in various wave conditions.

Table 5. Dynamic loads summary.

Load types	*Condition*	*Symbol*	*Numerical Value*
Loads due to the boat acceleration (inertial loads)	Wave motion – “b” case	$F_{W,X}$	37.5 kN
		$F_{W,Z}$	54.8 kN
	Wave motion – “d” case	$F_{W,Y}$	46.0 kN
		$F_{W,Z}$	3.7 kN

III. MAIN COMPONENTS DIMENSIONING

As mentioned before, the structure design phase has concerned mainly the upper framework, the petals and the landing surface covering. Particular care has been taken in the selection of the materials. The choice has been made considering the necessity to design a framework which should be as light as possible, compatibly with the structural strength. To avoid possible vibration issues during operations, the natural frequencies of the whole structure have been evaluated.

3.1. Materials

The required processing technologies have been considered of fundamental importance in the materials definition. In order to realize the complex geometries of the upper and lower frameworks, the use of welded metal profiles or properly folded and welded sheet metal has been adopted. In order to grant the structural strength, ferrous and non-ferrous metal alloys with high mechanical characteristics have been taken into account: particularly, the high strength steel alloy DOMEX 700® and the titanium alloy Ti-6Al-4V (ASTM grade 5) have been adopted. The DOMEX 700® steel alloy shows high mechanical properties, along with good weldability and a low overall price, although it is not a stainless alloy: a painting or galvanizing treatment is required to assure protection from maritime corrosion. Moreover, considering that it is a steel alloy, the final weight would be excessive. Alternatively, it is possible to consider the adoption of the high resistance, stainless steel alloy MLX17 (X1CrNiMoAlTi). Focusing on the target of mass reduction, the final choice has been the titanium alloy Ti-6Al-4V, which presents a much lower density than that of the steel alloy (Table 6), along with superior mechanical qualities with respect to DOMEX 700® steel and an excellent resistance to generalized corrosion. The welding process of this kind of alloy results however critical, due to the possibility of introducing high residual stresses in the weld seam and since this allow exhibits a fragile behaviour, due to its notch sensitivity. As prescribed by the applicable technical standards, it is indeed needed to realize full seam welding in inert environment, providing an appropriate relaxation procedure of the weld seam itself. As of the pins of the connecting hinges, considering the high level of acting stresses in these components, a stainless, high strength 17-4PH (AISI 630) steel alloy has been chosen. Eventually, for the covering of the surface, composite structures have been examined, including sheets and profiles in 6082-T6 aluminium alloy, or laminated carbon fibre, Kevlar, glass fibre and expanded polymer foam. The main mechanical characteristics of the materials proposed in the design phase are reported in Table 6.

Table 6. Main mechanical characteristics of the materials considered during the design phase.

Class	Designation	Density [kg/m^3]	E [MPa]	R_s [MPa]	R_m [MPa]	A%
Steel	DOMEX 700®	7870	206000	700	950	10-12
Titanium	Ti-6Al-4V	4430	113800	1090	926	10-16
Steel	MLX17 (X1CrNiMoAlTi)	7800	195000	1590	1500	12
Steel	17-4PH (AISI 630)	7800	197000	1158	1117	16
Aluminium	6082 – T6	2700	70000	310	250	10
Expanded polymer foam	Baltek Airex C70.200®	200	175	/	6	30
Carbon fibre	Grafite T-300®	1800	230000	/	3200	/
Glass fibre	TESPE -E®	2500	74000	/	3500	/
Kevlar	Grado K49	1500	130000	/	2900	/

3.2. Dimensioning and verification of the upper framework

The upper framework consists of welded beams, forming a hexagonal surface. A possible realization of the upper framework (3) provided of petals (1) and connecting hinges (2), is presented in Figure 6.

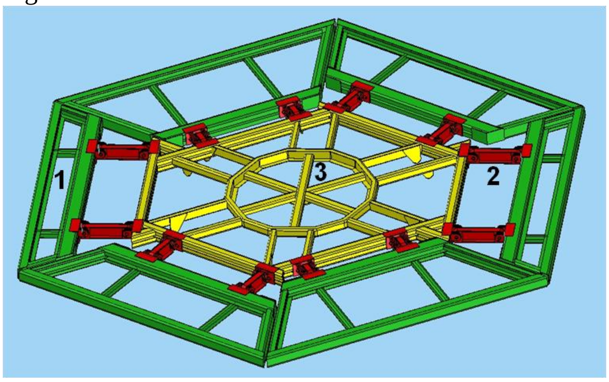
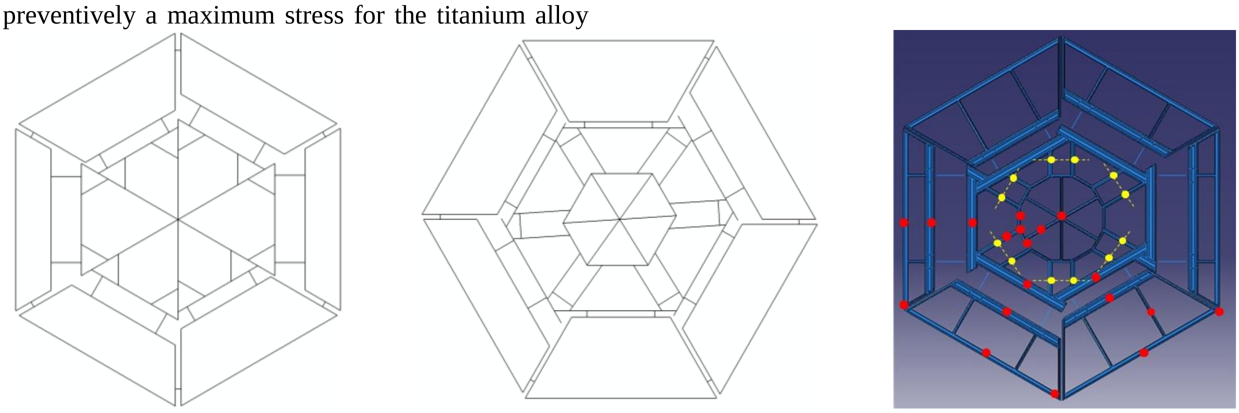


Figure 6. Example of a possible realization of the upper structure.

The initial phase of the upper framework design consisted in the selection of the optimal geometry, in order to identify a configuration which could grant at the same time the structural strength and a reduced mass. This kind of optimization has been performed by finite elements numerical analysis, using a commercial code. Simplified models with one-dimensional *beam* elements have been developed to describe the framework structure and the maximum equivalent von Mises stress has evaluated in every beam, as the lattice geometry changed, considering preventively a maximum stress for the titanium alloy equal to 700 MPa. The framework has been constrained, in the column attachment points, with conveniently directed ground hinges, and different load conditions, including the most critical situation in which the emergency landing in the further edge of the petal is simulated. To obtain the punctual forces values, one could refer to the precedent paragraph which deals with the load analysis. The different truss structures are shown in Figure 7 (a, b and c) while the loads and constraints scheme applied on the optimized configuration is reported in Figure 7(c). From the preliminary simulation it has been emerged that the displacement at the point of application of the loads results too high in order to grant a horizontal landing surface. Although not prescribed by the standards, it has been decided to adopt technical solutions in order to reduce as much as possible this deformation. The displacement at the extremity of the petal is mainly caused by the rotation of the edge beam sections. Since it has not been possible, due to functional and to space amount reasons, to arrange a strut, constrained to the ground or to the columns, which would support the petal by engaging it in its middle point, an executive configuration which would reduce the rotations induced by the torques applied to the beams themselves has been chosen instead. The edge beams of each petal have been then splitted, in order to transform what was a torque on the single beam in two parallel shear forces, thus stimulating the beams in bending instead than in torsion.



a) b) c)

Figure 7. Examples of the different analyzed truss configurations (a, b) and detail of the constraints (yellow dots) and the applied loads (red dots) considered for the optimized configuration.

FEM models with two-dimensional shell elements have then been developed in order to evaluate the effectiveness of this solution, and they have highlighted an overall reduction of the superior petal displacement higher than 10%. The acting forces scheme on the double beam configuration is presented in Figure 8(a), while in Figure 8(b) the vertical displacements numerically obtained from this solution are displayed.

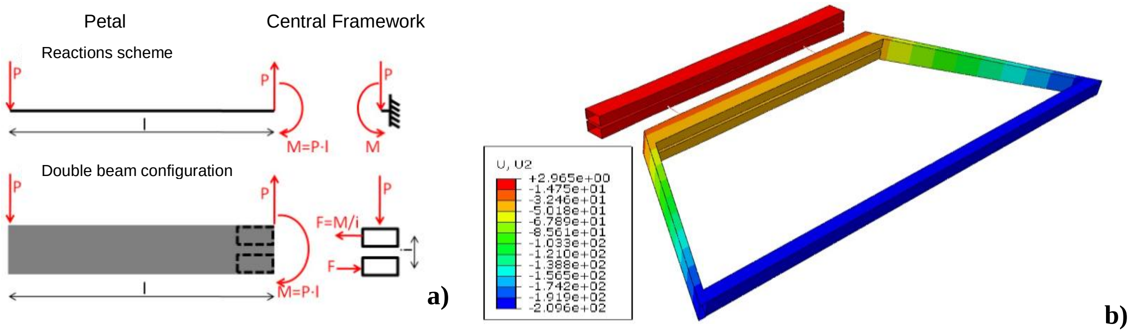


Figure 8. Double beam configuration scheme (a) and resulting displacement from the FEM analysis (b).

The optimized framework has been verified in detail, by developing accurate three-dimensional FEM models, with more than two millions degrees of freedom, and by simulating in detail even the behavior of the petals-frame links, by adopting suitable connectors. In the final configuration of the structure, further technical devices have been adopted, in order to uniform the stress state and to reduce the petals height. In particular, the connections between the framework beams and the petals beams have been obtained with structural nodes realized by welding metal sheets with large fillet radii. In this way, the presence of dangerous notches and complex welding points was avoided. The petals have been subdued to a further optimization, by realizing the radial beams with a tapered section (Figure 9b). An additional critical aspect of the platform in question regarded the possible onset of vibrations during the landing manoeuvre of the helicopter, which could invalidate the correct functioning of the self-levelling system and generate dangerous oscillations of the platform itself. The entire platform structure has then been analyzed with three-dimensional *shell* elements systems, in order to evaluate its natural vibrational modes, and to verify that its natural frequencies would not be harmful. In order to increase as much as possible the value of the minimum natural frequency, the structure has been further strengthened, by expecting the use of bracing ropes between the upper and the lower frame, each of which preloaded with a 10kN force. In Figure 10, the natural vibrational modes of the structure corresponding to the first (4.7 Hz) and the second (8.7Hz) natural frequencies are shown.

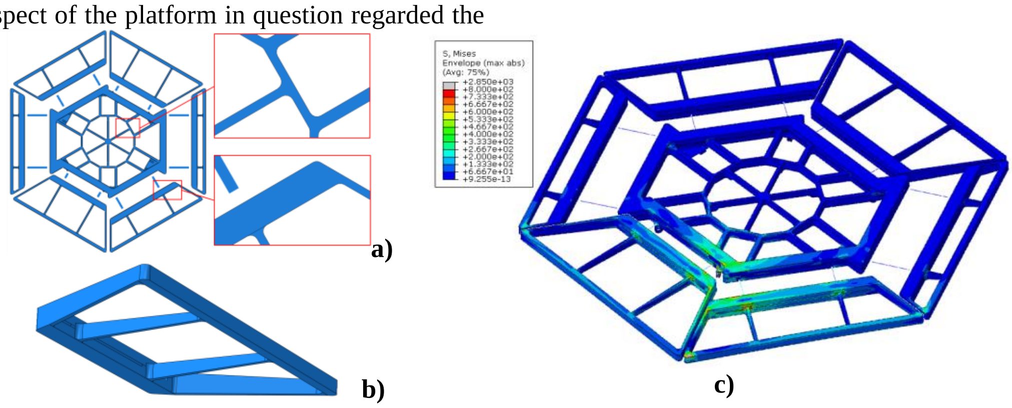
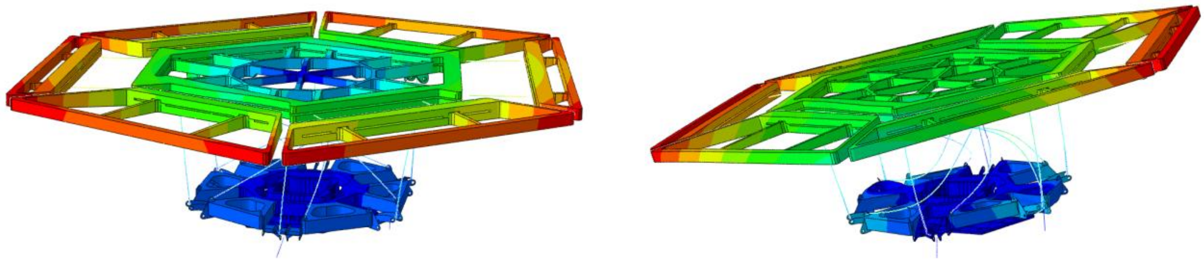


Figure 9. View of the upper framework, with filleted nodes (a) and of the petal with tapered beams (b). Final configuration resulting von Mises stress [MPa] contour in the most critical load condition (c).

Although the first natural frequency results lower with respect to the forcing frequency, it is of torsional sort – the upper frame tends to rotate with respect to the inferior base – and it was therefore tolerated since it was considered to have little influence on the superior surface levelling. The second natural frequency is instead of bending nature, but its value is higher than the imposed limit, hence it is not resonant with the forcing.

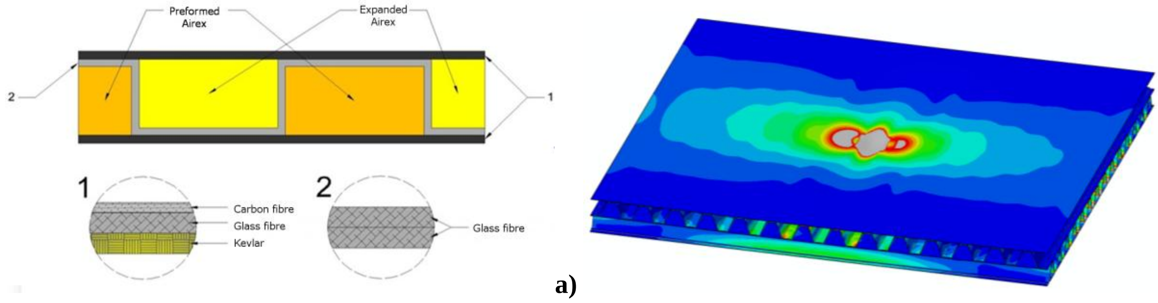


a) **b)**

Figura 10. Platform eigenmodes, corresponding respectively to the first (a) and the second (b) natural frequency.

3.3. Covering

A further critical aspect of the platform design has regarded the verification of the covering of the landing surface. This covering must show indeed sufficient strength, in order to sustain the parking loads, and to resist to the emergency load conditions without showing failures. At the same time, however, the covering must be light enough, so as to not increment the overall platform mass. For this reason, two different “sandwich” configuration were analyzed: the first realized through a superposition of 6082 –T6 aluminium alloy foils and profiles, the second composed by carbon fiber foils filled with Airex C70.200 foam. The verification has been conducted with three-dimensional FEM simulations, by applying a punctual load, representative of the emergency conditions, and by verifying that the failure of the whole section of the composite panel did not occur. For the covering version realized in aluminium, models with elasto-plastic material behaviour have been developed. As an example, a scheme of the stratification of the composite material covering is shown in Figure 11(a), while the stress distribution caused by the emergency load for the aluminum covering is presented in Figure 11(b). The results of the numerical analysis have highlighted the good behaviour of both the aluminium structure and the carbon fiber composite covering, as well as the importance of the geometry and the disposition of the aluminium profiles and the preformed expanded polymer foam filling shapes. Eventually, considering the overall mass, the performed optimization allowed to obtain mass values of 37 kg/m^2 and 8 kg/m^2 respectively for the aluminium covering and for the carbon fibre composite shielding.



a) **b)**

Figure 11. Stratification scheme of the composite material covering (a) and stress distribution caused by the emergency load for the covering realized with aluminium sandwich.

IV. CONCLUSIONS

In this work the design of a mobile self-levelling platform to be installed on medium and large-sized yachts has been described. The structure in question can be destined to different purposes, among which as a mobile platform for the landing and parking of helicopters. Since the latter is the most onerous condition from the structural point of view, it has been considered as reference in the dimensioning and verification of the main components. Particular care was taken in the analysis of the technical standards, in order to evaluate the acting loads in the standard operative conditions, and appropriate emergency conditions have been considered. Given the particular task of this structure, the design constraints imposed on mass and dimensions have necessitated the adoption of adequate technical solutions and of materials which combined high strength with lightness. The most critical components have been analyzed with the help of numerical investigation techniques which allowed their optimization. The performed verifications permitted to define a lattice beams structure realized in Ti-6Al-4V titanium alloy, reduced overall mass and high resistance to the aggressive environment in which the platform is employed. The adopted constructive solutions, from the point of view of the framework geometry and of the beams disposition, have allowed the reduction of the acting stresses and of the overall deformations. The natural frequencies of the structure have been then evaluated, in order to verify the absence of dangerous dynamic phenomena during the operations. Eventually a covering of the external surface has been designed, considering the use of both aluminium light alloys and of a carbon fibre and expanded polymeric foam structure.

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