Design of a hoistable helicopter platform for 60m yacht

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I declare that this thesis and the work presented in it are my own and have been generated by me as the result of my own original research.

Where I have consulted the published work of others, this is always clearly attributed.

Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.

I have acknowledged all main sources of help.

Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma.

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ABSTRACT (English)

Aesthetic and geometrical constraints are undersigning the key problems in a full certification of a new helideck on a commercial yacht. The complexity it is also governed by the “linkage” that has to be done between the two different operational industries, yacht and aircraft.

Each “flight-capable” vessel is certified for operations with specific helicopter. Before a vessel is certified for a particular helicopter, the entire landing area must pass through a brief structural analysis, to ensure that the decks structure will safely support the operations of the helicopter.

Nowadays it can be found just one example which successfully accomplishes a fully certification for its landing area, the AIR, 81m Motor Yacht.

Guidance for landing area design considerations are given in UK Civil Aviation Authority Paper 2004/02, included in the MCA’s, LY2 rules, and the structural safety is governed by Lloyd’s Register SSC Rules.

Hereby the requirement of the research is to design a foldable helideck, creating an aesthetically “link” between the helideck and yacht. The vessel is a 60 m motor yacht; the chosen helicopter is an EC 120, carrying 4 passengers and one pilot.

The work presents a brief structural design, direct FEM analysis and theoretical calculations, and mainly mechanical design. The theoretical and FEM calculations carried out showed a good agreement in using aluminum extrusions in construction of a helideck. The analysis carried out determines the resulting stresses on the helicopter deck structure imposed by the helicopter operations during worst emergency landing condition. The calculated stresses are in safe parameters compared to permissible values imposed by rules.

The foldable helideck is composed from 5 main parts (one fix, and 4 foldable). The motion between the helidecks movable parts is imposed by hydraulic pistons.

For a full certification of the landing area, furthermore is mandatory to consider environmental effects-involving CFD analysis-and intact and minor damage (vessel less than 85 m) stability test.

PRESENTAZIONE (Italiano)

I vincoli estetici e geometrici sono i principali problemi per la completa certificazione di un nuovo ponte elicottero a bordo di uno yacht. La complessità è dovuta anche ai due differenti sistemi di operatività provenienti dai costruttori di yachts ed aeroveicoli.

Ogni nave con la predisposizione per l'atterraggio di un elicottero è certificata per tali operazioni con uno specifico elicottero. Prima che la nave sia certificata, l'intera area di atterraggio deve passare attraverso un'analisi strutturale affinchè la struttura del ponte risulti sufficientemente sicura per le operazioni dell'elicottero.

Ad oggi, l'unico esempio di area di atterraggio completamente certificata è quella a bordo dello yacht a motore di 81m "AIR". Le linee guida per la progettazione dell'area di atterraggio furono date dalla UK Civil Aviation Authority Paper 2004/02, incluse nella regolamento LY2 dell'MCA, mentre il dimensionamento e la messa in sicurezza della struttura fu approvato tramite il regolamento Lloyd's Register SSC.

La tesi mira ad illustrare il progetto di un ponte elicottero incernierato, creando un connubio estetico tra lo yacht e il ponte elicottero stesso. La nave è uno yacht a motore di 60m; l'elicottero scelto è un EC 120 omologato per trasportare quattro passeggeri e un pilota.

Il lavoro presenta un breve progetto strutturale, analisi FEM, calcoli teorici e principalmente considerazioni e studi di carattere meccanici. I calcoli FEM e teorici promuovono l'utilizzo dei profili di alluminio estrusi per la costruzione del ponte elicottero. Le analisi eseguite evidenziano le sollecitazioni risultanti alle quali sono sottoposte le strutture del ponte durante le peggiori operazioni di atterraggio d'emergenza dell'elicottero. Le sollecitazioni calcolate rientrano nei parametri di sicurezza richiesti dai regolamenti vigenti.

Il ponte elicottero mobile è composto da cinque parti (una fissa e quattro incernierate). Il movimento delle parti incernierate del ponte elicottero è guidato da pistoni idraulici

Inoltre, per una completa certificazione dell'area di atterraggio, è necessario considerare il comportamento della nave in particolari condizioni climatiche-atmosferiche attraverso le analisi CFD e la sua stabilità in condizioni di integrità e di falla per navi inferiori a 85m.

ABSTRAKTE (Deutsch)

Entwicklung einer höhenverstellbaren Hubschrauberplattform für eine 60 m Jacht Ästhetische und geometrische Beschränkungen sind die Hauptprobleme bei der Zertifizierung einer Hubschrauberplattform auf einer kommerziellen Jacht. Die Komplexität wird außerdem erhöht, da eine Verbindung zwischen zwei unterschiedlichen Industrien, Luft-und Schifffahrt hergestellt werden muss.

Jedes „flugfähige“ Wasserfahrzeug ist zertifiziert für den Betrieb mit einem bestimmten Hubschrauber. Vor der Zertifizierung eines Schiffs für einen bestimmten Hubschrauber, muss die gesamte Landefläche strukturell analysiert werden, um sicherzustellen, dass die Struktur den Landeoperationen eines Hubschraubers standhält.

Aktuell gibt es nur einen Fall, in dem eine Hubschrauberlandefläche vollständig zertifiziert wurde, die AIR 81 m Motorjacht.

Richtlinien für die Landeflächenkonstruktion sind im UK Civil Aviation Authority Paper 2004/02 und in den MCA LY2 Regeln gegeben. Die Strukturelle Sicherheit wird über die Lloyd’s Register SSC Regeln bestimmt.

In dieser Arbeit besteht die Anforderung darin, ein faltbares Hubschrauberlandedeck zu konstruieren, das einen ästhetischen Zusammenhang zwischen der Jacht und dem Hubschrauberdeck darstellt. Bei den Fahrzeugen handelt es sich um eine 60 m Motorjacht und einen EC 120, ausgelegt für 4 Passagiere und einen Piloten.

Die Arbeit beinhaltet eine strukturelle Konstruktion, eine FEM Analyse und eine theoretische Kalkulation. Die theoretische Kalkulation und die FEM Analyse des Hubschrauberdecks zeigen eine gute Übereinstimmung bei der Verwendung von Aluminium-Extrusionsprofilen. Die durchgeführte Analyse bestimmt die auftretenden Belastungen innerhalb des Hubschrauberdecks bei der Landung eines Hubschraubers unter schwierigsten Bedingungen. Die berechneten Belastungen liegen innerhalb der Sicherheitsgrenzen, verglichen mit zulässigen Belastungswerten.

Das faltbare Hubschrauberdeck besteht aus fünf Hauptteilen (1 befestigt, 4 faltbar). Die Bewegung der faltbaren Teile wird durch hydraulische Kolben durchgeführt.

Für eine vollständige Zertifizierung der Hubschrauberlandefläche sind weitere Untersuchungen notwendig (zum Beispiel CFD), in denen Umwelteinflüsse berücksichtigt werden- und eine kleine Stabilitätsanalyse.

1. INTRODUCTION

1.1. Overview

In the early 60's yacht industry starts his first clear steps in Europe. From size to weight from technology to beauty, these words could derived to infinity, but probably a proper word will not be found which could define this "phenomenon" called yacht. The evolution of this industry in the past 50 years it was remarkable, a short visit to a large presentation event such like Monaco's Yacht Show can prove this evolution in everybody's eyes. Casting a sweeping glance over the densely packed harbor, one of the first things that it can be notice are the numerous helicopters tethered to the aft deck of yachts (See fig.1).

Figure 1.Example of helicopters on aft – sundeck on a yacht

Fast and agile, but extremely delicate, helicopters have become an integral part in super yacht operations. The number of these yacht examples is increasing from year to year according to specialists in a couple of years reaching already the incredible number of 100 unique examples.

Until just the idea of the "landscape" exist everything seem easy and wonderful, looking from technical point of view everything is complicating suddenly. To be able to understand better this wonderful transport technology implemented in the yacht industry, everything it must be disassemble in small parts.

Starting from the beauty of the described “landscape”, a first aspect as mentioned is the beauty, which is the ambient linkage between a helicopter and a yacht, to be able to give this aesthetic to this kind of application it has to be accomplished a set of rules.

As it known, commercial yachts (charter) have to satisfy statutory rules, such as LY2. Yachts aesthetics obviously do not match with the geometric requirements of a helideck; the design need accomplish something which fulfills two important aspects, the aesthetics and the MCA (Maritime and Coastguard Authority) requirements. MCA its giving the LY2 code, which ANNEX 6 is defining the “TECHNICAL STANDARDS FOR HELICOPTER LANDING AREAS”. This technical standard defines the geometrical standard of a landing area, and its safety assessment.

From structural point of view Lloyd Registers rule book was used, mainly using the Volume 4, Part 6 - Hull Construction in Ships, 5th Chapter, in which Section 5,6, and 7 it can be find the safety structural requirement of a helideck.

All the description related to applicable rules for design a new helicopter deck it can be found in the first Chapter of this research.

1.2. State of the art

Nowadays, the vast majority of the super yachts are designed and built to operate as "Commercial Yachts", which means that they are able to be chartered by a maximum of 12 passengers. In order to ensure the safety of the employed crew and the passengers, large yachts are subject to regulatory frameworks, the most famous being the MCA Large Yacht Code. The original code set the rules concerning fire protection, lifesaving appliances, stability and protection of personnel, trying to Taylor SOLAS and Load Lines requirements to a particular vessel such as a yacht, but the possibility to adopt a helicopter for transferring guests to and from a yacht was not taken into account.

For the owner or a passenger of a yacht, however, the helicopter is not an unusual vehicle: they often take a helicopter to reach the yacht directly from their business activities.

The increase in demand leads the MCA to amend the Large Yacht Code in 2007, including the safety design and operational requirements in the Annex VI (see LY2- which sets the requirements for helideck's for commercial operations).

Considering the hazards involved in helicopter operations, and the experience gained on offshore, navy and commercial ships, the Annex VI has no or little relaxations compared to offshore helidecks. They are therefore very demanding, matching the safety of helicopter operations with the profile of a luxury yacht. As a matter of fact, there are only a very few yachts with a certified helicopter landing area. The rest of the helidecks that can be seen on board of many yachts are not fully certified, and they could only be used when the yacht is not engaged in commercial operations, at the owner's or pilot's risk, but they grant no safety to the persons on the helicopter or onboard the vessel, and often insurances will not cover any accident.

1.3. Work purpose

The task therefore is to design a certified helideck, for a 60 m yacht. The aesthetic of the landing area it has to be fitted in the already existing design aesthetic of the given vessel, therefore the helideck it has to be a foldable one. It will be a "Touch and Go "operational helideck, the landing area will be used just for a short operational time, for example the helicopter will bringing the guests, and after will departure, after this operation the helideck it has to be hidden while is not in use. The designed has to be consisted from some moving parts which will make the structure foldable, and hidden will helicopter operations are not required.

This foldable aspect it has to be done in such a way to fulfill aesthetic and design rule considerations, such as structural and safety.

The fulfillment of this proposal involves 3D modeling, structural design (made by rules and direct FEM analysis), and mainly mechanical design.

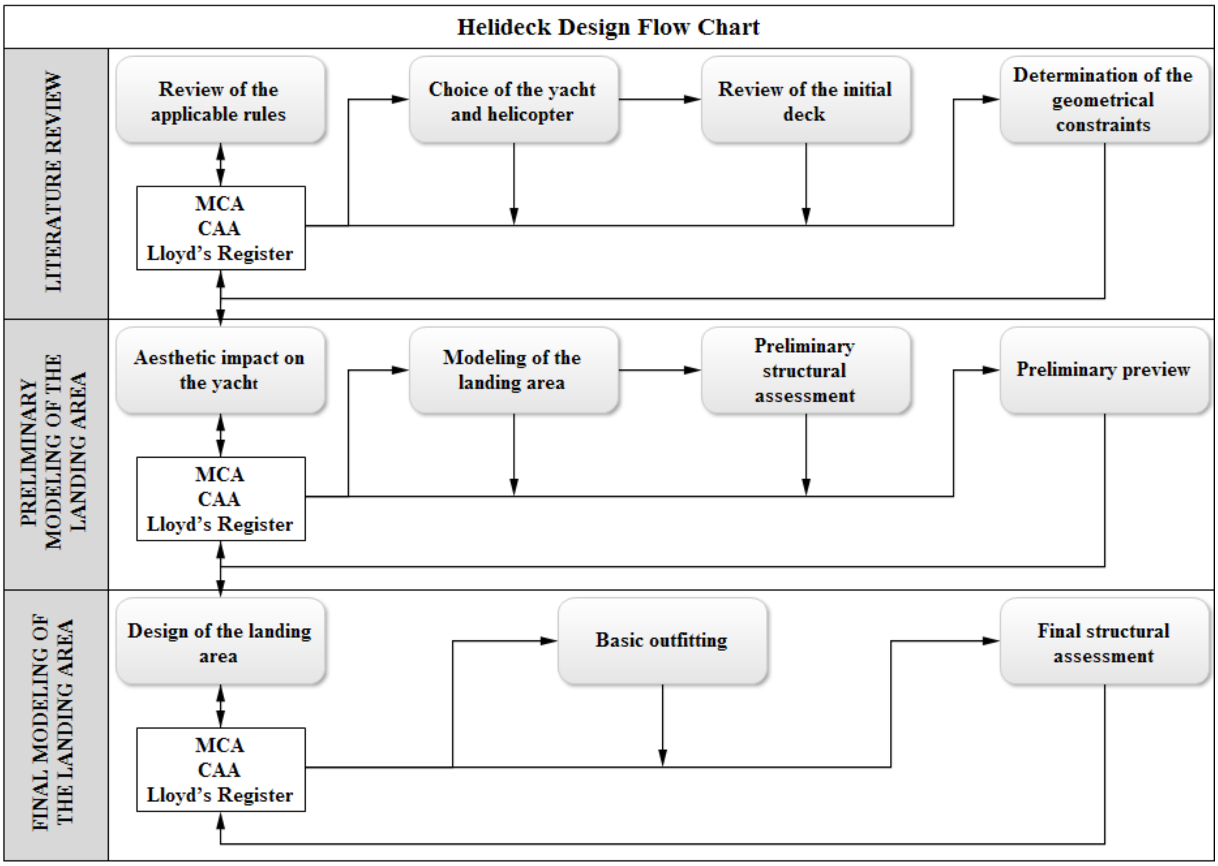

Figure 2.Helideck design-flow chart

Fig.2 shows the general work flow of a certified helideck, proposed and developed during this research. The wok flow "mechanism" is also described in Thesis structure section, where importance of each component of the chart is highlighted.

1.4. Background

Unfortunately there are no precise examples to a certified helideck, but as mentioned the 81m Motor Yacht AIR's helicopter deck is complying the requirements of a fully certification, but without giving an aesthetic solution. Another solution it may be the Besenzoni's Helybase solution, presented in fig. 3.

Figure 3.Besenzoni's Helybase concept

Unfortunately needier these solution is not offering any good example for the task, not being fully certified helideck.

Therefore the task is to use the use the CAP [2004] paper, which defines design issues concerning helidecks for offshore use and following the rules to accomplish the request of this research.

1.5. Thesis structure

As it was already showed in the Work purpose section, fig.2, the developed chart it will be followed. Therefore, in order to undertake design problems, it should be followed steps; which can simplify, increase results accuracy, and most importantly can help in understanding much clearly issues in which helicopters are involved during offshore operations. One good theoretical example is the CAP [2004] paper, which describes the entire issues encounter by a helideck designer and how to avoid them. Passing through these well predefine steps by the CAP [2004] it may be notice the difficulties involved already in really early design stage of a helideck.

Like a workflow proposal of this research it could be taken in consideration some mandatory steps, as it has been showed in fig.2, which should be followed as example during the design stage of any landing are. First of all, it was considered a brief review of the applicable rules, which can give answers for design issues that landing area designers may encounter and should overcome for a safety operation. After defining properly the rules, “boundaries” which are applied for the design of a any new landing area it can be known exactly which are the limitations that a designer should consider in his further work. Defining precisely the “boundaries” of this research the next step is to see where these are applied. It shell be done a brief overview of the vessel, from this to be fine to optimum position where the landing area in could be fitted. Having the geometrical position of the new landing area on the vessel, the helicopter can be chosen, taking in consideration all the geometries of the vessel around the location where the helideck will be fitted, the helicopter carrying capacity, and the geometrical dimensions of the helicopter. All these decisions are affecting directly the further steps of the design, for example having a small geometric size for the helicopter; it gives a smaller weight, which automatically resumes to a smaller structural strength for the landing area; and also less weight, less geometrical size for the helideck, but also but not necessary less carrying capability. The type of the helicopter landing “support” it is also really important, considering a gear landing or slink “support” for the helicopter is changing the structural analysis of the landing area, every each of them mechanically has different impact on the landing area, the obtained results will be different and also differently interpreted.

Going further, having already a chosen helicopter, it can be given according to the rules a first preliminary design, covering the main geometrical dimensions of the landing area. Knowing the helidecks main geometrical dimensions, his position on board, a first preliminary sketch can be done, following precisely the requirements of the CAA thought the

LY2 code from the MCA attendant. Once the CAA approved the with the proposal of landing area, geometrically, and the safety operation of the helicopter during his operation on board the vessel is not compromised, then further design steps can be followed.

The preliminary structural assessment can be started, following the LR rule book, the minimum thickness of the structure plating and stiffeners spacing is defined. The rules are not giving any restriction for the type of the material from which the landing area shell be constructed, the only requirements according to the rules is the contact face of the landing area with the landing “support” of the helicopter, the material must be non-slip material, but this request nowadays can be really easily fulfilled, having an elaborated painting technologies.

After passing thought the preliminary structural assessment a first preliminary 3D solution in can be given. Having the 3D solution for the landing area structural analysis it has to be performed, taking in consideration the worst condition that the helideck may encounter, in contact with the helicopter and his operational environment. The helicopter worst conditions considerations are not properly predefine, concerning this it will be taken in consideration the smallest area of the helicopter landing “support” that may touch the structure during an emergency landing. This contact will result the most considerable efforts on the landing area. The contact position on the landing area is considered on the biggest area limited by stiffeners. The worst boundary condition will considered also for the contact area limited by stiffeners, which is a simply supported plate on all the 4 edges. The resulted values will be the worst considered, and these shell be compared with the limit values given as well by the LR rule book.

Knowing that the helideck has to match aesthetically with the yacht, this will request further 3D modeling, in order to obtain the foldable solution for the helideck. The technical solution results has to fulfill again all the safety requirements by the rules. Right after giving a technical solution it shell be done detailed functional description, in order to include all the details in the final structural assessment, which consist an overall FEM analysis, with which the efforts on the foldable mechanism shell be analyzed, during the helicopters worst landing condition.

2. LITERATURE AND PRELIMINARY REQUIREMENTS

2.1. Review of the applicable rules (MCA-LY2, CAA and LR)

2.1.1. Introduction

The goal of undertaking the design of any new yacht is to take a unique set of requirements and owner requirements and combine them in such a way to can obtain the best possible solution to those requests, following world wild predefine rules, such as MCA LY2, CAA, and Lloyds Register or ABS (both of them are covering landing area structural safety assessments, but in this work the structural analysis as it was mentioned, it was based on LR structural requirements).

The applicable rules are serving like "design boundary" in the modeling faze of a new helideck. In order to define an applicable rule to a ship, it is mandatory to identify the classification class in and from which is he belonging to. Knowing since the beginning the information related to the vessel on which the new landing area has to be implemented, it gives the first applicable rules. Being over 24 m long, less than 3000 GT, used for commercial use for sport or pleasure, carrying less than 12 passengers, the MCA's (Maritime Coastguard Authority) code LY2 it was used in the certification of the existing 60 m yacht. The structural assessment is done by following Lloyd's Register rule book.

The following sections are covering the importance of each rule applicable in design of a new landing area.

2.1.2. MCA (Maritime and Coastguard Authority)

In 1997, the Agency published, it's Code of Practice for the Safety of Large Commercial Sailing and Motor Vessels (LY1), which provided a "Code" approach for vessels which where unsuited to the application of conventional Merchant Shipping Regulations.

LY1 was given statutory force by the Merchant Shipping (Vessels in Commercial Use for Sport or Pleasure) Regulations 1998. This notice sets out the revised text of the Code of Practice for the Safety of Large Commercial Sailing and Motor Vessels which will for simplicity now be entitled the Large Commercial Yacht Code (LY2).

LY2 replaces the original Code under provisions of regulation 2(2) of the Merchant Shipping (Vessels in Commercial Use for Sport or Pleasure) Regulations 1998, as amended. The provisions of LY2 require standards of safety and pollution prevention, which are appropriate to the size of the vessel. The standards are set by the relevant international conventions and equivalent standards are applied where it is not reasonable or practicable to comply with international conventions. Large means 24 meters and over in load line length and the Code of Practice applied to yachts which are in commercial use for sport or pleasure, do not carry cargo and do not carry more than 12 passengers.

This Code of Practice has been developed jointly by the United Kingdom, its relevant overseas territories and international industry representatives. Where ‘Administration’ is used in the Code, it means the Government of the State whose flag the ship is entitled to fly. Vessels are required to comply with the various merchant shipping regulations of the Administration which are relevant to the class of vessel to which they belong.

Vessels in commercial use for sport or pleasure do not fall naturally into a single class and, in any case, prescribed merchant ship safety standards may be incompatible with the safety needs particular to such vessels.

The “Code of Practice for the Safety of Large Commercial Sailing and Motor Vessels”, or LY1, was introduced in 1998. The Code applies to vessels in commercial use for sport or pleasure, which are 24 meters in “load line” length and over. Or, if they were built before July 1968, are 150 gross tons and over, according to the tonnage measurement regulations at that date. Such vessels are not permitted to carry cargo, or more than 12 passengers.

The code sets standards of safety and pollution prevention, which are appropriate to the size and operation of the vessel. For vessels of this size, standards are normally set by the relevant international conventions. The Code provides equivalent standards, as permitted by these conventions where it is not reasonable or practical to comply with the prescriptive requirements of the international convention.

As with the Codes for small vessels, it was recognized that LY1 would have to be revised to take account of advances in technology and changes of practice. This revision has taken place in consultation with the Large Yacht Industry. All comments from that consultation have been considered by Working Groups comprising experts from the international large yacht industry.

The new Code, now known as The Large Commercial Yacht Code, or LY2 for short, came into effect on 24th September 2004. LY2 has now been revised and is available as Merchant Shipping Notice MSN 1792.

The revision process was designed to fine tune the original Code, rather than change the fundamental requirements, and as such the basic philosophy remains the same. Possibly the most significant change in LY2 is the introduction of the category “Short Range Yacht” for those vessels that cannot, or have no operational need to, meet the ‘Unlimited’ criteria. This is particularly relevant to high-powered yachts with large engines that do not meet the subdivision and ‘damage survivability’ requirements in relation to engine-room flooding.

The parameters for Short Range Yachts are: Less than 300 GT (for new vessels); or Less than 500 GT (for existing vessels); Operation up to 60 miles from a safe haven (this may be increased to 90 miles on specified routes with the agreement of the Administration); and Operation within favorable weather – Force 4 by forecast/actual.

MCA LY2 landing area section description (see Annex 1), will give us the design boundaries of the Helideck.

2.1.3. CAA (Civil Aviation Authority)

The CAA is the UK's specialist aviation regulator. Through its skills and expertise it is recognized as a world leader in its field. Its specific responsibilities include:

- Air Safety;
- Economic Regulation;
- Airspace Regulation;
- Consumer Protection;
- Environmental Research & Consultancy.

CAA defines the safety statutory rules for helicopters and airplanes. Guidance for landing area design considerations are given in UK Civil Aviation Authority Paper 2004/02 which should be consulted by designers of helicopter landing areas at the earliest possible stage of the design process and is available through the CAA .

The objective of CAA Paper 2004/02 is to help designers of helicopter landing areas to create topside designs and helicopter landing area locations that are safe and ‘friendly’ to helicopter operations by minimizing exposure to environmental effects. It is hoped that, if used from the outset of the design process when facilities are first being laid out, this manual will prevent or minimize many helicopter landing area environmental problems at little or no extra cost to the design or construction of the vessel.

2.1.4. Lloyd’s Register

The Lloyd's Register Group is a maritime classification society and independent risk management organization providing risk assessment and mitigation services and management systems certification. Historically, as Lloyd's Register of Shipping, it was a specifically maritime organization. During the late 20th century, it diversified into other industries including oil & gas, process industries, nuclear and rail (source Lloyds Register).

Lloyd's Register provides quality assurance and certification for ships, offshore structures (landing areas) and shore-based installations such as power stations and railway infrastructure. However, Lloyd's Register is known best for the classification and certification of ships, and inspects and approves important components and accessories, including life-saving appliances, marine pollution prevention, fire protection, navigation, radio communication equipment, deck gear, cables, rods, and anchors.

Regulatory standards within all aspects of the energy sector have become more stringent and countries are paying more attention to construction issues and structural integrity. Prediction of structural integrity in response to extreme stress is vital to not only meet new standards but to also safeguard any operations.

Therefore, as it was already mentioned, the Lloyds register will serve as structural design guideline, all the obtained structural results will be compared with the allowable ones defined in the Rules and Regulations for the Classification of Special Service Craft, in order to receive a structural certification for the new landing area.

Mainly the volume 4 of the rule book has been followed, covering the requirements of chapter 5 – special features, section 5 and 6 helicopter landing areas. Chapter 7, failure modes, was applied as structural safety design boundary control.

2.2. Choice of the yacht and helicopter

2.2.1. Introduction

Fast, agile, but also extremely delicate: Helicopters have become an integral part of super yacht operations. The number of these fascinating, high-maintenance, airborne tenders – just like their size – is growing.

Today, more and more super yachts are being equipped to carry helicopters, which can be a wonderfully convenient, time-saving, comfortable and stylish, not forgetting a safe form of transport. With the ability to take-off and land almost anywhere, helicopters can pick guests up from an airport directly to the yacht or rapidly transport passengers from the yacht to any city or specific place, thus saving time otherwise wasted in congested traffic.

Passengers can spend their time onboard the helicopter relaxing comfortably whilst enjoying the unobstructed view of the surrounding scenery. For business executives who want to make full use of every single minute, the time in the helicopter can also be used for business purposes and meetings thanks to the presence of state-of-the-art info-communications technology onboard.

The main advantage of travelling by helicopters aboard a yacht is therefore to save time, providing yacht owners with the opportunity to spend more time afloat or for sightseeing purposes in remote areas. A helicopter can also provide them with the possibility of replenishing supplies or with the pleasures of heli-skiing for the more adventurous. Moreover, for yacht owners who are qualified pilots, the pleasure of flying would itself be a highly-valued part of the holiday.

All the above render a helicopter the perfect flying tender to a yacht and not just an extra accessory to have onboard. Today, the use of helicopters on yachts is facilitated by the presence of a growing number of companies which offer yacht owners a turn-key helicopter service including logistics and support activities. Yacht owners can now choose to possess helicopters either through long-term purchase or short-term lease.

2.2.2. Choice of the Yacht

2.2.2.1. Mega yachts and Charters

A 45 to 50 meters (148 to 164 feet) luxury charter yacht, the smallest with a generally accepted claim to super yacht status, will usually be a three decker with cabins for 10-12 guests (12 is the usual maximum number of guests, due to licensing regulations, as it is very expensive for a luxury charter yacht to obtain the licensing necessary to carry more than 12.), and for a crew of a similar size. The accommodation on this type of luxury charter yacht is typically as follows:

- Lower deck: exterior swimming platform at the stern; four (sometimes five) guest cabins with en-suite bath or shower rooms aft; engine room amidships; crew quarters forward.
- Main deck: sheltered exterior deck aft leading into the salon; dining room and galley; entrance amidships; owner's suite forward, usually includes either a study or a second twin stateroom.
- Upper deck: exterior deck aft, often used for outdoor dining; second salon (often called the sky lounge); staffed bar inside or outside or both; sixth stateroom will be amidships if it is not on the lower deck or part of the owner's suite; gym (may also be on the lower deck or part of the owner's suite); captain's cabin; bridge.
- Sun deck: on the roof of the upper deck, often features a Jacuzzi.
- A 50 meter luxury charter yacht will have one or more luxury charter yacht tenders for reaching shore and other "toys" which may include a speed boat or sailing boat, jet-skis, windsurfing and diving equipment and a Banana boat. Up to date yachts have multiple flat screen televisions and satellite communications.

The number of very large luxury charter yachts has increased rapidly since the 1990s and increasingly only luxury charter yachts above around 65 meters (213 feet) stand out among other luxury yachts. A luxury charter yacht of this size is almost always built to individual commissions and costs tens of millions of dollars (most luxury charter yacht super-yachts cost far more than their owners' homes on land, even though those homes are likely to be among the largest and most desirable). A luxury charter yacht of this size usually has four decks above the water line and one or two below. It is likely to have a helicopter landing platform. Apart from additional guest cabins, which are likely to include one or more "VIP suites" besides the owner's suite, extra facilities compared to a 50 meter luxury charter yacht will include some or all of indoor Jacuzzis, sauna and steam rooms, a beauty salon, massage and other treatment rooms, a medical center, a discotheque, a cinema with a film library, plunge pool (possibly with a wave-maker), a playroom, and additional living areas such as a separate bar, secondary dining room, private sitting rooms or a library. There will be more boats and "toys" than there are on a 50 meter yacht.

As of 2006 a luxury charter yacht above 100 meters (328 feet) are still sufficiently rare, but increasingly more common, that many luxury charter yacht enthusiasts can name them all. They typically have five decks above the water line and two below. The very largest luxury charter yacht will often incorporate such features as helicopter hangars, indoor swimming pools and miniature submarines. The burgeoning number of "small" super yachts has led to the introduction of the hyperbolic terms Mega Yacht and Giga Yacht to demarcate the elite luxury charter yacht.

2.2.2.2. BENETTI FB255, 60 m, Steel and Aluminum

The chosen model for the task of this research is the Benetti standard design, FB255 (see fig), a 60 m commercial charter. The first model of this design was lunched this year, in the beginning of 2011. The vessels hull is made from steel and the superstructure from aluminum, a more detailed description of the vessel about the scantling and technical description is elaborated in chapter 3.

The yacht is included in the Large Commercial Yachts category, they're certification is given by the rules describe in the first chapter of this research.

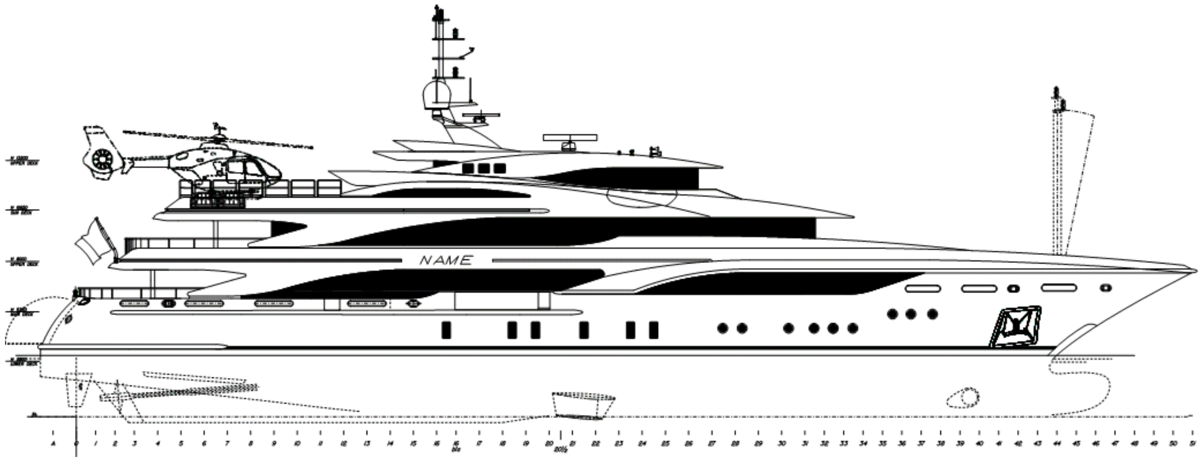

Figure 4.Initial yacht side view

2.2.3. Landing area

2.2.3.1. General Helicopter Operations

The operation made by a helicopter can give critical answers on crucial question during the beginning design stage of a new helideck. Landing area location and helicopter orientation are bidirectional and directly connected key parameters in the early design stages of a new helideck, one critical question may be, how should be positioned the helicopter on the deck? Which is the best place on a yacht to implement the new structure?

Helicopters usually land in the designated circle from the landing area, but during special operations may also land outside this circle. Therefore this deck must be analyzed for landing anywhere. “Loading” suggests in several points.

The orientation of the helicopter with respect to the ship affects the loading acting on the deck structure. Usually ships such as frigates or destroyers, and auxiliaries normally have small flight decks, due to this fact helicopters are landing on this decks with a certain angle with respect to the ship, and also location variations are limited. An a yacht case all this are much more different, helicopters must land on decks even longitudinally or transversally with respect to the ship, location also may vary over the length and breadth of the ship, but overall this mentioned boundaries on a yacht the most important factor is the aesthetic, this important parameter change everything. The location affects the magnitude of load. The orientation determines how the individual structural member must be loaded. Assume that the longitudinal or athwart ship orientation produces grater loading condition than angled orientation. Concerning this, during a new helideck analysis it has to be considered only longitudinal and athwart ship orientations.

Weather conditions which limit helicopter operations may vary according to the rules imposed by the operations manual approved by the aviation board or authority for the particular helicopter and its equipment.

Another issue is the landing condition, which defines the operation status of a helicopter; helicopters are to land and transit only in light condition.

2.2.3.2. Determination of the landing area location

The first requirement in the early design stage of a new helicopter landing area is to identify a location where the helicopter could land without any safety risks. This location should be where there is clear access to the operating area and exit from it to the ship's side. Once that location has been identified, the second requirement is to establish the best position within the area for the maneuvering zone that will give the largest clear zone.

Positioning of landing or winching areas (usually are included helicopters which operational time is longer, in the analysis case made is insignificant, due to the requirements, which is desired for a touch and go operation, in which case the helicopter will bring the guest and after that it will departure) close to the bow is not recommended due to the increased air flow turbulence created by the ship's passage (see fig. 5).

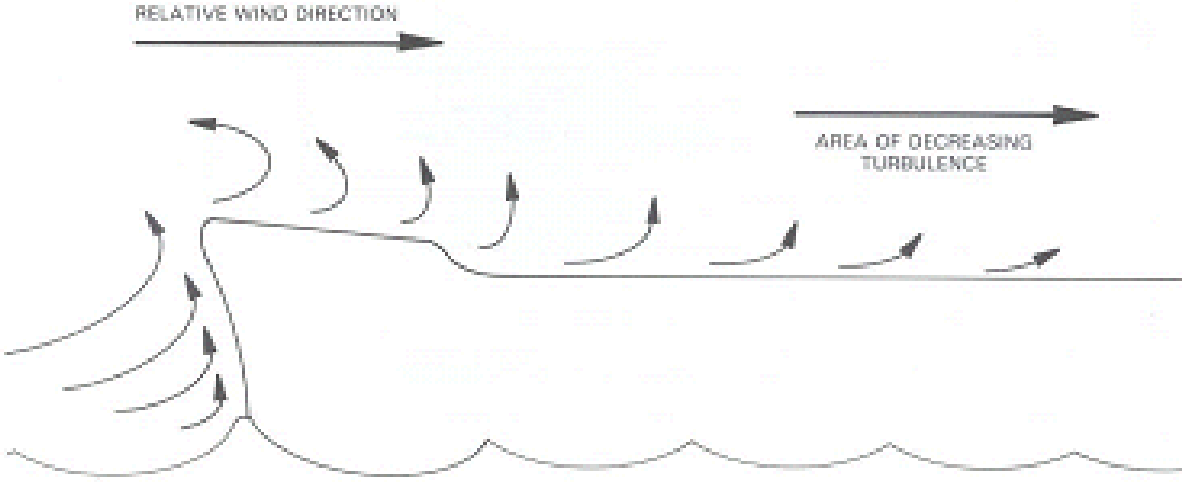

Figure 5.Turbulent flow induced by wind

According to people with good experience "Helicopters can land anywhere, if the landing space has the required size" (Martin Hager, *TOUCHDOWN FOR DINNER*). But since the yacht's superstructure, masts and the funnels with their hot exhaust fumes create air turbulences that interfere with the airflow to the rotor blades, helicopter pilots would prefer the helipad as far away as possible from these aerodynamic problem zones. Ideally, the helicopter landing area should be a dedicated deck used solely for the purpose. This means using valuable real estate aboard the yacht, which often becomes a conflict between a dining area, an area to relax and a dedicated helideck. Only on the largest yachts can this be easily resolved.

The two other common areas to utilize are the upper aft deck or the fore deck, but both places have their disadvantages. On the upper deck aft, the helipad is often small and the tail end of the helicopter, including the tail rotor, juts out from the deck, making the required pre-flight inspection of the entire helicopter impossible. Owners and shipyards like to place the helipad on the fore deck. "This is, quite frankly, the cheapest piece of real estate aboard the yacht," says Nigel Watson, owner of the helicopter consultancy. "No-one will place a dining table or a sun lounger there." Pilots, however, do not like the fore deck at all. As the bow lies far away from the yacht's center of gravity, the boat's yaw, roll and pitch are far more pronounced here than anywhere else. This movement, together with wind shear off the bow and the difficulties of visual referencing make this a less than ideal location. To assist both the master of the vessel to understand the limitations of his helicopter deck and report these to the air crew, a movement sensor has to be installed below the helipad. Data from this together with atmospheric conditions like air-pressure, temperature, wind direction and speed, allow the helicopter operation to maximize the possibility of a safe take-off or landing. Fore deck landing areas are more dangerous because of a lack of visual references. You are flying into the wind, which normally means that the vessel is at best at your side and at worst visually behind you and below. Therefore you cannot easily see what you are landing upon.

Loss of horizon relates to the problem of spatial disorientation. The sky blends into the sea and you can very quickly reach a point where you do not know what is up or down. You can no longer rationalize what control inputs to make, which may result into your flying a perfectly good helicopter into the sea. In order to assist in standardizing the approach to the vessel, some yachts are nowadays equipped with high-tech landing aids, such as a glide slope indicator (GSI), a gyrostabilizer prismatic light source, which offers a standard glide slope for an inbound helicopter to approach the vessel. This is particularly helpful in inclement weather conditions.

2.2.3.3. Landing area size

The geometrical constraints (see subsection 2.4) are highly critical for a fully certification of a helideck, and rare in examples in yacht applications world wiled. Due to the duty that yachts are carrying out, they have restricted area for a fully certified landing area. The perfect and the only example existing nowadays is the Koninklijke De Vries Feadship, launched and christened the 81m Motor Yacht AIR at their Aalsmeer shipyard in Holland on Saturday the 26th of March 2011. Super yacht AIR measures a colossal 81 meters (265.7 feet) and is the largest yacht ever to be built at the yard.

A certified helideck should be of sufficient size to provide adequate ground effect and load bearing area to enable normal take-off and landing and for maneuvering in the hover to position for passenger handling.

2.2.4. Choice of the Helicopter

2.2.4.1. Helicopters

Helicopters are a perfect complement to business jets by being the ideal ‘first mile, last mile’ solution for getting between mid-town and the airport, thus providing the crucial missing link in end-to-end transportation scenario. In this way, modern-day business executives can optimize their time onboard for meetings which would otherwise be wasted during on-ground traffic congestion.

The fact that many helicopters operations take place throughout the world every day underlines the inherent safety and usefulness of the helicopter.

Marine helicopter operations demand a clear understanding of safety requirements for both the ship and the aircraft. Twin engine helicopters are always to be preferred for helicopter/ship operations. Single engine helicopters should only be used for transfers to ships on which a suitable recommended landing area is available. In some cases, national and international regulations may stipulate the use of twin engine machines.

The helicopter operator must comply with the aeronautical requirements for helicopter operations and pilot standards of both the country of registration of the helicopter and the country where it is operating. It mandatory that helicopters must be operated in accordance with the instructions in the operations manual prepared by the helicopter manufacturer, and approved by the Administration, for the aircraft concerned.

The aircraft is maintained to a schedule recommended by the manufacturer and approved by the appropriate aviation Authority, some of whose requirements may be additional to those to the manufacturer. The aviation Authority will also have inspectors to check regularly that the operator is applying the rules and regulations correctly.

The safety of the helicopter remains at all times the responsibility of its pilot. He should be aware of the maneuvering limitations of the ship. It is essential that there is full understanding and agreement between the ship’s master and the helicopter pilot on a clear and simple plan of arrangements both prior and during operations.

The following criterion is based on helicopter size and weight. This data is summarized in Table 1 below. Where skid fitted helicopters are used routinely, landing nets are not recommended. Mainly these are the existing helicopters used for passenger transportations:

Table 1- D-Value and Helicopter Type Criteria (Not exhaustive)

Type	D value	Perimeter	Rotor	Max	't'	Landing
-	(m)	'D'	Diameter	Weight	Value	Net size
-	meters	marking	(m)	(kg)	tones	-
Eurocopter EC120	***11.52***	***12***	***10***	***1715***	***1.7***	***Not required***
Bell 206 B3	11.96	12	10.16	1451/1519	1.5	Not required
Bell 206 L4	12.91	13	11.28	2018	2	Not required
Bell 407	12.61	13	10.66	2268	2.3	Not required
Eurocopter EC130	12.64	13	10.69	2400	2.4	Not required
Eurocopter AS350B3	12.94	13	10.69	2250	2.3	Not required
Eurocopter AS355	12.94	13	10.69	2600	2.6	Not required
Eurocopter EC135	12.1	12	10.2	2720	2.7	Not required
Agusta A119	13.02	13	10.83	2720	2.7	Not required
Bell 427	13	13	11.28	2971	3	Not required
Eurocopter EC145	13.03	13	11	3585	3.6	Not required
Agusta A109	13.04	13	11	2850	2.9	Small
Agusta Grand	12.96	13	10.83	3175	3.2	Small
Eurocopter AS365 N3	13.73	14	11.94	4300	4.3	Small
Eurocopter EC155 B1	14.3	14	12.6	4920	4.9	Medium
Bell 430	15.29	15	12.8	4218	4.2	Medium
Sikorsky S76	16	16	13.4	5318	5.3	Medium
Agusta Westland 139	16.66	17	13.8	6400	6.4	Medium
Bell 412	17.1	17	14.02	5398	5.4	Not required

The Eurocopter EC120, is the most used in this kind of application, also his dimensions are acceptable. Due to the given small space available on the sundeck the only alternative is to choose a small size helicopter, therefore the choose helicopter is the Eurocopter EC 120.

2.2.4.2. Eurocopter

"Given their flexibility and their ability to take-off and land nearly everywhere, helicopters are multi-purpose vehicles offering a wonderfully convenient, time-saving, comfortable and stylish, not forgetting a safe form of transport for both business travels as well as for leisure", says Mr. Patrice Royer, Eurocopter Market Development Director for the Business Aviation /VIP and Commercial segments. He adds, "At Eurocopter, all our helicopters are equipped with the state-of-the-art technology which translates into high cruise speed, exclusive comfort, on-board communication devices, low noise signature, executive appearance etc."

Created in 1992 from the merger of the helicopter divisions of Aerospatiale-Matra (France) and Daimler Chrysler Aerospace (Germany), the Eurocopter Group is now a whollyowned subsidiary of EADS (European Aeronautic, Defense and Space Company), one of the top three aerospace companies in the world. Through successive integration phases, the group has now become the first totally integrated aeronautics company in Europe. Currently, only three entities exist: the parent company Eurocopter, its German subsidiary Eurocopter Deutschland, and now the group's third pillar, its Spanish subsidiary Eurocopter Spain. This set-up allows the group to profit from a unified command structure, while at the same time insuring respect for the national identities of the participating countries.

In addition, Eurocopter offers its helicopters as the perfect flying tenders for yachts. Today, more and more super yachts are being equipped to carry helicopters, which can pick guests up from an airport directly to the yacht or rapidly transport passengers from the yacht to any nearby city.

2.2.4.3. Eurocopter Colibri EC120 B

The smallest member of the Eurocopter family is the single-engine civil light helicopter EC120 B Colibri seating five; it is suitable for training pilots as well as for rescue and monitoring services. Advanced design, the use of the low-noise “Fenestron” tail rotor as well as of composite materials are some of these helicopter's features.

Figure 6. Eurocopter EC 120 during operation

It was presented to the public worldwide for the first time in early 1997. According to official measurements by the International Civil Aviation Organization (ICAO), the EC120 B Colibri is the quietest helicopter in its class. Enhanced environmental compatibility is also achieved by the new engine, which leads to far less pollutant emission than with older helicopter types in this class. CATIC of China and Singapore Technologies Aerospace are involved in the development and production of the EC120 Colibri.

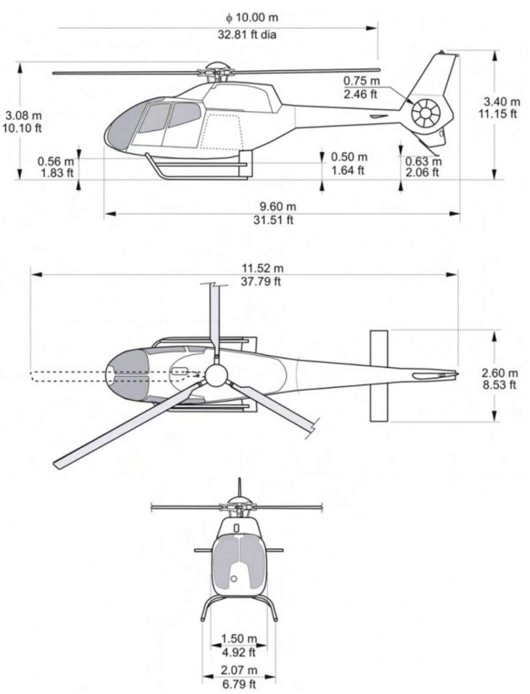

Figure 7.Technical description of the helicopter EC 120

General Characteristics

Layout

- Passenger transport - 1 pilot + 4 passengers or 2 pilots + 3 passengers;
- Casualty transport - 1 pilot + 1 paramedic and 1 stretcher-patient;
- Cargo carrying - 1 pilot + 2.94 total useful load volume (cabin and hold).

Weights

Table 2- Helicopter weight variation

	Weight
	kg
Empty weight, baseline aircraft ***1***	994 ***2***
Useful load ***3***	721
Maximum take-off weight	1,715
Maximum cargo sling load	700
Maximum operational weight in external load configuration	1,800

1 Baseline aircraft empty weight includes oil and unusable fuel. Ballast plates can be added at the rear of the FENESTRON, their mass is 19 kg maximum. The baseline helicopter is delivered as standard with 6.3 kg ballast weight that is not included in the basic empty weight.

2 Empty weight according to baseline aircraft definition.

3 The useful load does not include the ballast plates. Depending on the configuration, the ballast's weight will be deducted from the useful load.

2.3. Review of the initial deck

2.3.1. Introduction

Structural analysis is the prediction of the performance of a given structure under prescribed loads and/or other external effects, such as support movements and temperature changes. The performance characteristics commonly of interest in the design of structures are stresses or stress resultants, such as axial forces, shear forces, and bending moments; deflections; and support reactions. Thus, the analysis of a structure usually involves determination of these quantities as caused by a given loading condition.

The objective of this section is to present the choose yacht initial structure (sundeck) scantling and general structural assessment. This simple review will help in understanding of the initial structural design, and forward help in design of the new structure.

Knowing the fact that the landing area will be implemented in the sundeck's structure (established in Chapter 2, Section 2.3), first of all it should be made a small overview over the generalities of a sundeck on a yacht. This will lead to a better understanding on the role of the sundeck, and also over parameters which may influence it and forward these could be a high risk influence over the overall structure of the yacht.

2.3.2. Generalities

The top decks of vessels were traditionally not very clean spaces due to the smoke/soot from the stacks and were therefore used as work areas, for storage of lifeboats etc. Modern exhausts are now fitted with excellent filtering systems and often exit on the hull side reducing noise and contamination. This trend has consequently allowed the top deck to become an ideal place for guests to enjoy the sun and have a Spa in a secluded ambiance away from the noise and passing traffic on the quays. There are many constructive solutions to Spa systems depending on the space available and the usage of the decks.

To design a sun-deck (relaxation deck or Spa) there are several areas to be considered as the stability of the vessel safety could be seriously affected. From the structural point of view it is important to know the ideal re-enforcement needed under the superstructure as the weight of a full Jacuzzi is considerable (considering a full Jacuzzi, which weight may have more than 5 tones). Often using an existing boat deck where the structure has already been modified to take the weight is a good option. A Spa also needs to adapt to its level automatically when several guests simultaneously enter it and return to its original level once these guests exit. This set up, with the pre-heated compensation tanks etc., needs to be fitted and dealt with by experienced personnel to assure a quality product, worthy of a Super yacht.

Yachts sun-deck mainly are used for relaxation, but also for helicopter landing area, considering these to important factors, design innovation is a decisive key upon a good quality result, to be able to combine strength with beauty.

2.3.3. Description of the initial deck

In order to understand the modification that are have to be made and implement the new structure on the already existing (predefined) sun-deck. The superstructure of the *BENETTI FB255* concept is made fully from aluminum, including the sundeck on which the new helicopter landing area most be integrated (See more details in Annex 2).

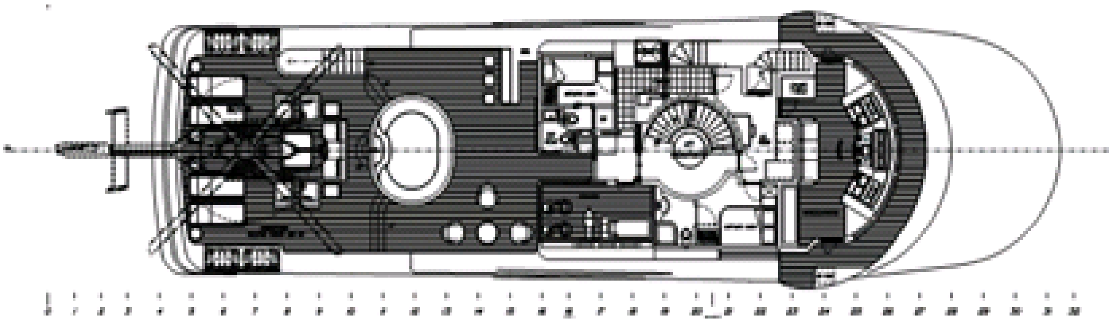

Figure 8. Initial sun-deck general arrangement

Fig.8 represents the initial sun-deck general arrangement, which help in understanding and in interpretation of the modification that it has to be done for implementation of the hoistable helideck.

The initial sun-deck overall length is approximately 36 m; to undertake the loading of the sundeck, steel pillars are fitted in the superstructure inside, between the upper deck and the sun deck, welded with bi-metallic joint; another two stainless steel pillars are fitted in the superstructure outside, between the upper deck and sun deck aft, welded with bi-metallic joint.

To be able to understand better the scantling of the initial helideck, it has to be reviewed the initial loads from this deck.

Initially the sun-deck was design for a “touch and go” landing area. This landing area wasn’t fully certificated helideck, due to the restriction of space and safety of landing.

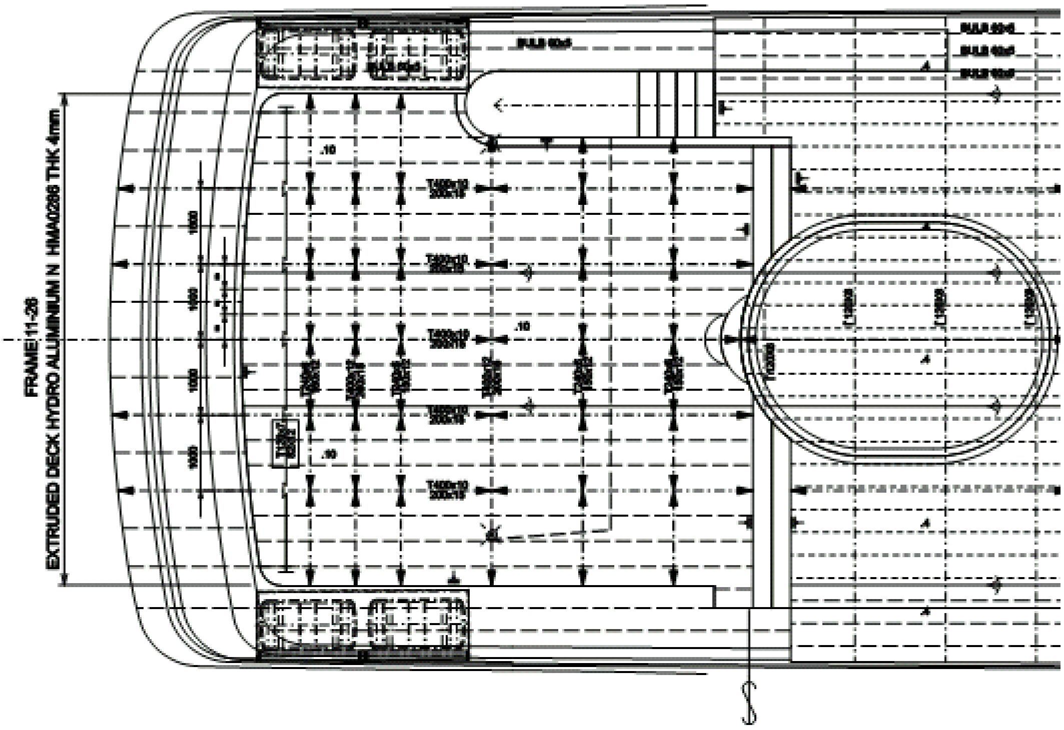

Figure 9.Initial aft sun-deck scantling

Fig.9-10 are representing the initial aft sun-deck scantling, where due to the fact that this deck was used as a helipad, plus safety and people loading in the scantling it can be identified:

- Five longitudinal girders(with a spacing of 1000 mm);
- This girders being reinforced transversally by two equally spaced transvers frames, as its showed in fig. 9 (1800 mm equal spaced);
- The secondary transvers members are 600 mm equally spaced from the primary transvers member, due to the requested landing area, coming forward(direction of bow) the spacing is increased, the secondary member space being doubled (1200 mm);
- Finally the secondary member of the longitudinal members, are equally spaced in between the primary longitudinal members(approx. 333 mm), and push through the transvers members longitudinally;
- The deck plating it’s 10 mm thick.

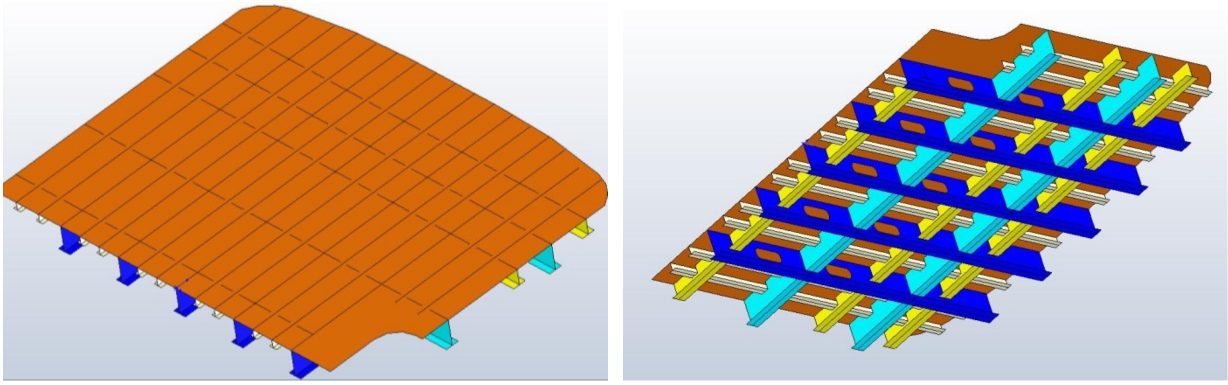

Figure 10. Virtual model 3D of the initial landing area

Furthermore a small analytical and theoretical structural analysis is carried out in order to check how the above presented structural behaves during the operations made by the helicopter upon the sundeck.

2.3.4. Theoretical structural assessment of the initial helideck

As it has been showed in the previous sub-section, the initial sundeck plate structural scantling is creating a maximum area unstiffened of 1000x500 mm. This area will be analyzed for local deformations. For the analysis the plate is considered as simply supported. As it has been mentioned before the sundeck structure base material is aluminum, therefore for aluminum properties, the lowest safety parameters are used, considering here the material yielding strength as 180 MPa.

As it was already introduced before, the chosen helicopter has slink landing gears, which mean that to consider the worst loading case to the structure, the slinks dimensions shell be defined in the best way possible. The rules which are covering design aspects of helicopter landing area are suggesting to request from the helicopter provider the dimensions for the slink, anyhow if these are not provided, two line loading of 300 mm can be considered. Now the final consideration that it was taken into account in this research is 300x64 mm loading patch. This was considered knowing the average dimensions of the particular chosen helicopters landing slinks, which is more or less 2000x80 mm.

Now this loading patch defines the worst landing condition for the helicopter, which is assumed to be the worst condition during landing encountered by the structure; this condition could happened when the helicopter is touching the structure just with one slink, and also from that one just on an area of 300x64mm. On this loading patch it will be distributed the weight of the helicopter, multiplying it with a safety dynamical loading of 2.5.

The total force through which the helicopter will touch the landing area can be defined as follows:

$$f_{ht} = f_h * S_{DC} \tag{1}$$

Where,

f_{ht} – the total force imposed by the helicopter;

f_h – force imposed by the helicopter, due to its weight;

S_{DC} – safety dynamic coefficient defined by LR rules, S_{DC}=2.5;

w_h – Helicopter total weight in kg, w_h=1800kg;

g – Acceleration gravity;

The force imposed by the helicopter due to its weight can be expressed:

$$f_h = w_h * g \tag{2}$$

$$f_h = 17658\ N$$

Therefore, substituting this in **Eq.** it can be obtained:

$$f_{ht} = 44145\ N$$

Distributing this total force induced by the helicopter and the dynamical safety parameter on the load patch:

$$p = \frac{f_{ht}}{(A_{LS})} = \frac{44145}{(300 * 64)} \tag{3}$$

$$p = 2.3\ \frac{N}{mm^3}\ \mathrm{N}$$

Where,

A_{LS} – area of the considered landing slink;

P –distributed pressure over the landing slink area.

This sub-section is not a mandatory task for the design of the landing area, but it can serve with some answers in order to create some ideas related to the new landing area strength, or even scantling. Therefore, thought the next tables are showed and furthermore interpreted the obtained result for this theoretical analysis. (Note that the same workflow is used further in the strength assessment of the new landing area, the only difference being the plate profile, therefore, just some physical characteristics will differ).

Table 3. Input data

Lx	Ly	t	α	H_{SL}	H_{SW}	F_H	S_{DC}	H_W	E	υ
[mm]	[mm]	[mm]	-	mm	mm	[N]	-	[kg]	[N/mm^2]	-
1200	333.33	10	2	300	64	17658	2.5	1800	70000	0.334

Where,

Lx – longitudinal length of the plate along x axis;

Ly – with of the plate, along y axis;

t – Plate thickness;

α – plate aspect ratio;

H_{SL} – Helicopter landing slink length;

H_{SW} - Helicopter landing slink width;

E - Young modulus of aluminum;

υ - Poisson's ratio.

After computing the developed workflow (based on Walter D. Pilkey, 2005,) it can be obtained:

Table 4. Initial landing area theoretical structural assessment results.

Case 1	w_max	M_x	σx	Vx	τ_max
	[mm]	[N]	[N/mm^2]	[N]	[N/mm^2]
	5.125	1.229E+03	131.024	136.406	2.728
Case 2	w_max worst	M_x	σx	Vx	τ_max
	[mm]	[N]	[N/mm^2]	[N]	[N/mm^2]
	7.049	1.690E+03	180.209	187.612	3.752

Fig.11 represents the above landing conditions analyzed, showing the geometrical distribution of the loading patch upon the surface of the plate for the two analyzed cases; where the first care is represented by hatched area patch, respectively the blank one the second case.

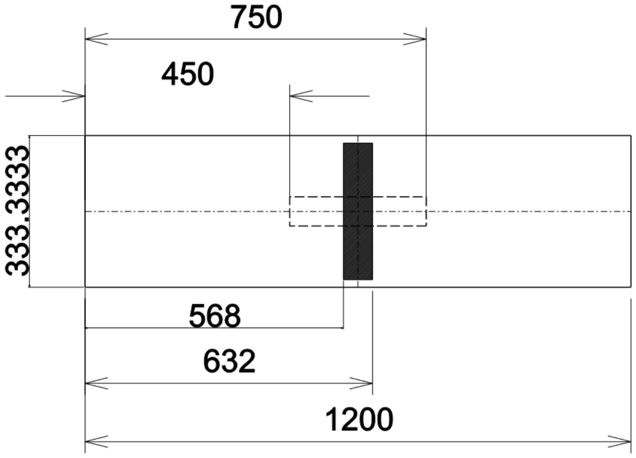

Figure 11.Loading patch upon the unstiffened plate

It can be noticed; that the stresses induced in both cases by the considered loading patch is relatively high, comparing to the yielding strength of the material. For the analysis performed just the reactions along the x axis, longitudinal length of the plate were considered, knowing that the structure is relatively simple, and its flexural rigidity will give relatively equal strength along both its directions, due also to his significantly small geometrical size.

The obtained results as it was mentioned are relatively high, therefore in the design of the new landing area, shall be taken in consideration the structural characteristics of the initial helideck, in order to avoid structural strength problems. Therefore, eventually plate thickness could be increased, or even reducing the stiffener spacing. But for this as it was mentioned, Lloyds Register rulebook offers a small workflow thought which the minimum plate thickness can be obtained.

2.3.5. Finite element method

Generalities

The Finite Element Method (FEM) has developed into an indispensable key technology, in the modeling and simulation of advanced engineering systems in various fields like housing, transportation, communications, and so on. In building such advanced engineering systems, engineers and designers go through a sophisticated process of modeling, simulation, visualization, analysis, designing, prototyping, testing, and lastly, fabrication.

Now, behind the finite element modeling method, (Joseph E. Flaherty and Amos Eaton, Finite element analysis, Lecture notes 2000), is a computational technique through which it can be obtained approximate solutions for partial differential equations that arise in scientific and engineering applications. Rather than approximating the partial differential equation directly, e.g., a finite difference method, the finite element method utilizes a variation problem that involves an integral of the differential equation over the problem domain. This domain is divided into a number of subdomains called finite elements and the solution of the partial differential equation is approximated by a simpler polynomial function on each element. These polynomials have to be pieced together so that the approximate solution has an appropriate degree of smoothness over the entire domain. Once this has been done, the variation integral is evaluated as a sum of contributions from each finite element. The result is an algebraic system for the approximate solution having a finite size rather than the original in finite dimensional partial differential equation. Thus like finite difference methods, the finite element process has discretized the partial differential equation but unlike finite difference methods, the approximate solution is known throughout the domain as a polynomial function and not just at a set of points.

Without referring to specific FEM software, whatever this could be, using a simple or a complex model, the analysis results and computational time will depend upon the technique used to set up a given model. Therefore, techniques related to modeling and simulation in a rapid and effective way play an increasingly important role, resulting in the application of the FEM being multiplied numerous times because of this.

So what is the FEM?(G.R.Liu and S.S.Quek, 2003)The FEM was first used to solve problems of stress analysis, and has since been applied to many other problems like thermal analysis, fluid flow analysis, piezoelectric analysis, and many others. Basically, the analyst seeks to determine the distribution of some field variable like the displacement in stress analysis, the temperature or heat flux in thermal analysis, the electrical charge in electrical analysis, and so on. The FEM is a numerical method seeking an approximated solution of the distribution of field variables in the problem domain that is difficult to obtain analytically. It is done by dividing the problem domain into several elements, depending upon the complexity and requirements of the application. Then physical laws are then applied to each small element, each of which usually has a very simple geometry. Then a continuous function of an unknown field variable is approximated using piecewise linear functions in each sub-domain, called an element formed by nodes. The unknowns are then the discrete values of the field variable at the nodes. Next, proper principles are followed to establish equations for the elements, after which the elements are ‘tied’ one to another. This process will lead to a set of linear algebraic simultaneous equations for the entire system that can be solved easily to yield the required field variable.

The helicopter landing and takeoff from the landing area surface brings across various concepts, methods and principles used in the formulation of FE equations in a simple to understand manner. The FE analysis is carried out using the well-known commercial software ANSYS.

Analysis

The virtual model was designed in Solidworks, taking in consideration just landing area upon the sundeck. All the initial features of the landing area plate scantling being considered and modeled as described in the previous sub-section. Shell elements were used to construct the virtual model, to reduce the computational time.

The boundary conditions were applied as much as possible like the real model, in order to describe the real sundeck behavior in case of an emergency landing of the helicopter (see fig.12). Therefore, the rear part of the sundeck was simply supported on the two side longitudinal girders due to the two pillars which are sub staining the sundeck. The front part of the sundeck being considered fixed, in reality presenting the same situation being fixed to the superstructure.

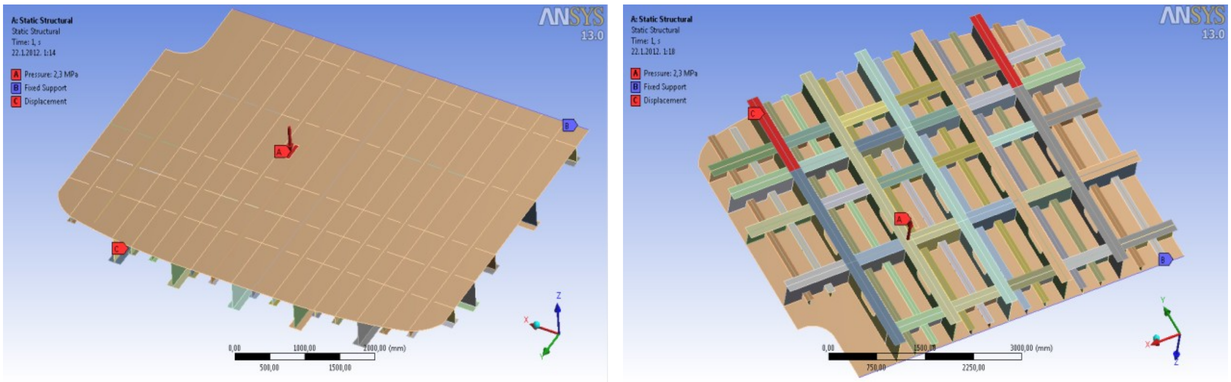

Figure 12.Virtual model boundary conditions and loading

The loading condition was applied in the same way as it has been showed in the previous subsection, 2.3 MPa, pressure which has been distributed on the considered helicopter slink area 300x64 mm.

Note that all the stiffeners, flanges and webs were considered 10 mm.

After all the connections were made, between the landing area plating and the reinforcements, an automatic mesh has been created. Automatic mesh made by Ansys showed inaccuracy, and relatively high structural errors, which means that the results were quiet far away from reality.

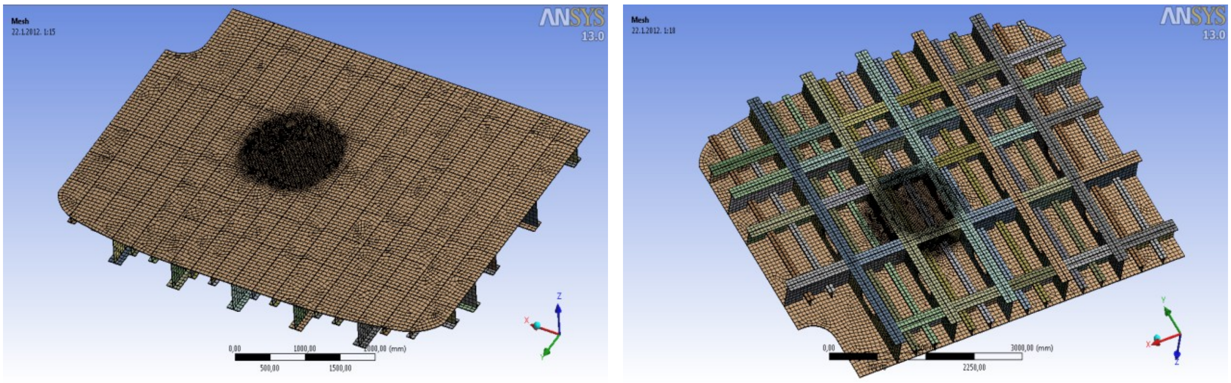

Figure 13.Mesh setup

In order to solve this problem, the accuracy of the mesh was increased around the analyzed domain, as it’s showed in fig. 12-13. Reducing the size of the mesh around the loading patch domain decreased significantly the number of structural errors, as it’s showed in fig.15-16.

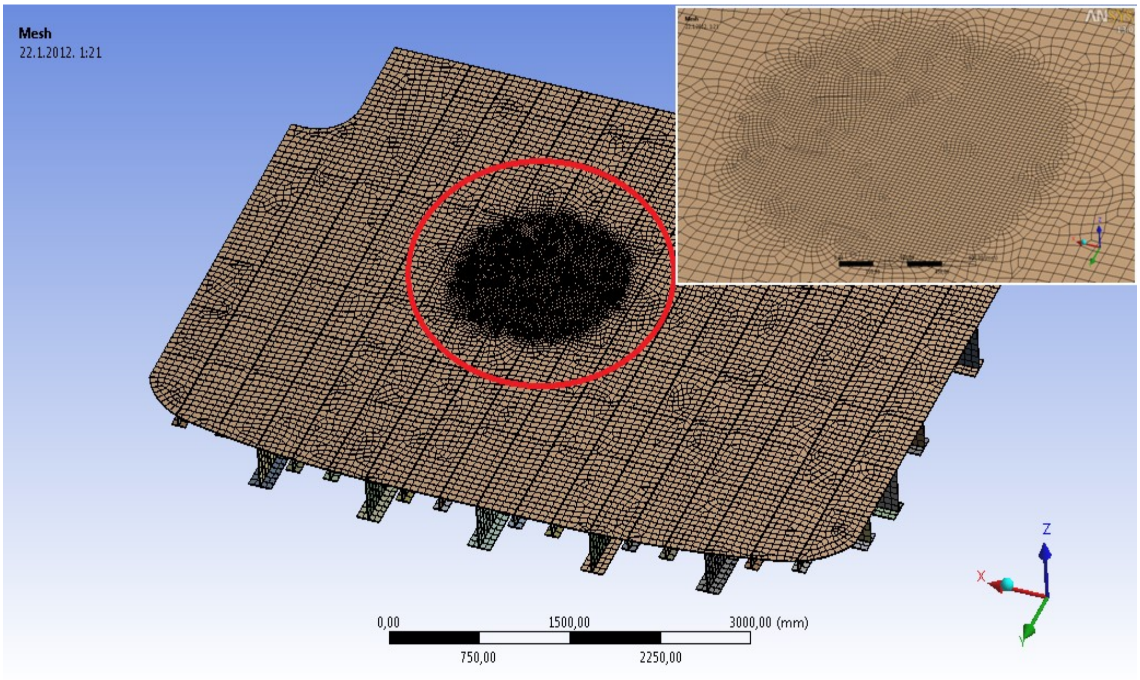

Figure 14.Mesh accuracy around the analyzed domain

This mentioned structural errors theoretically are really useful to identified regions with high structural error region, which as it was mentioned is helping to user to identified the region where the model would require a more refined mesh.

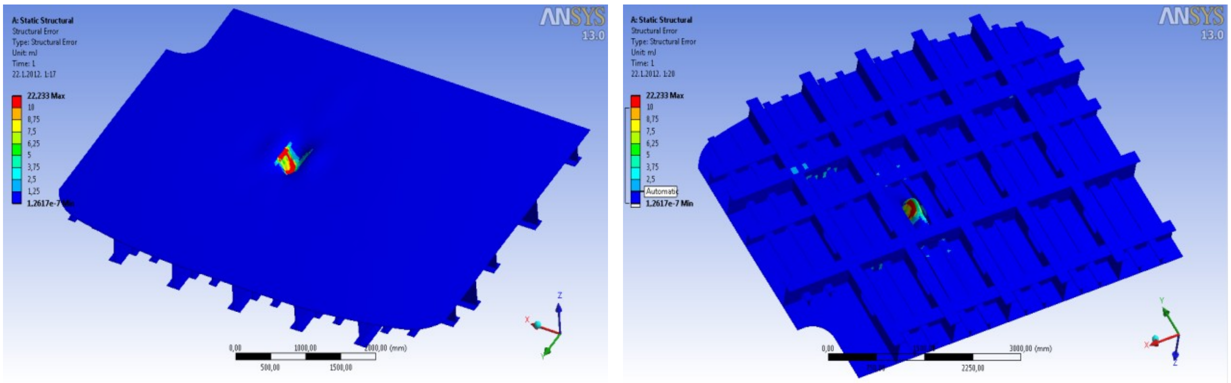

Figure 15.Structural errors distribution globally upon the structure

The showed structural errors, see fig.14-15, are based upon the difference between a smooth stress distribution within the analyzed domain, and actual stresses calculated by the FEM solver for each mesh element.

Looking on the more detailed fig.16 in can be notice that the maximum structural error regions are reaching a value of approximately 22, relatively close to the middle of the analyzed region. Note that the value of the structural errors is measured in energy format. But anyhow it can be also notice that in the region where the maximum deflection, and the maximum stresses are located, in the middle of the plate, the structural errors are significantly small, barely reaching 2-3 structural errors. Therefore in can be assumed that the obtained stress distributions results are quiet accurate. Usually people with experience in structural FEM analysis, are considering that structural errors values upon 10 can be acceptable, and the obtained results can be considered accurate enough.

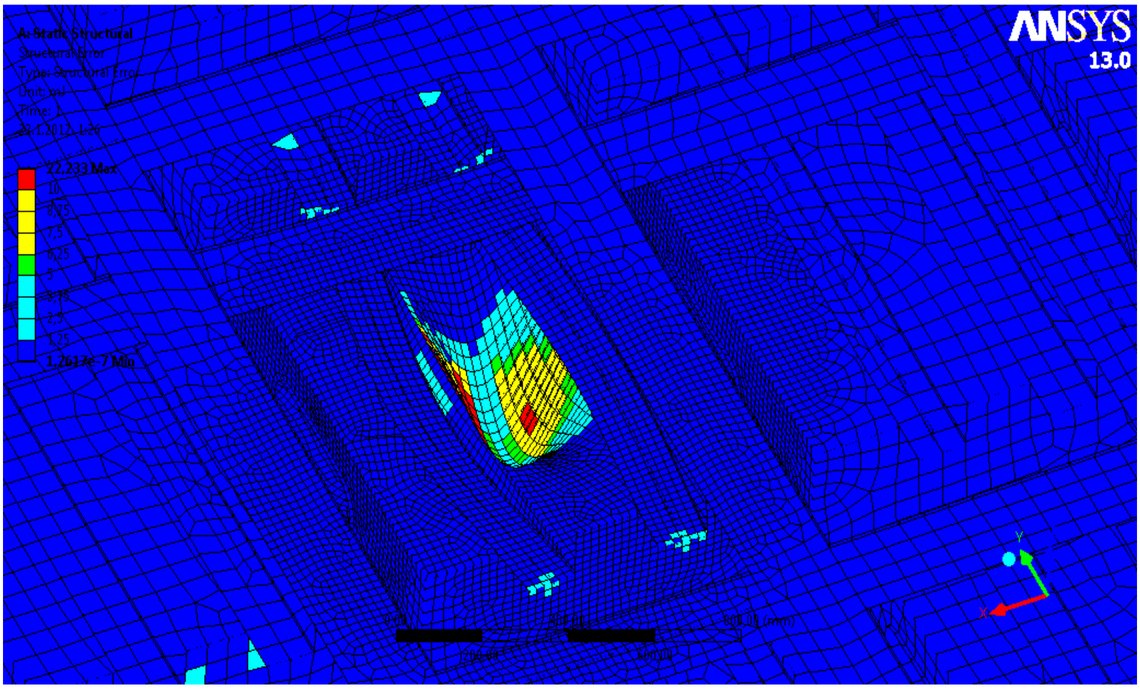

Figure 16.Structural errors distribution

In fig.17-18 it can be seen the deflection of the structure due to the landing slink loading.

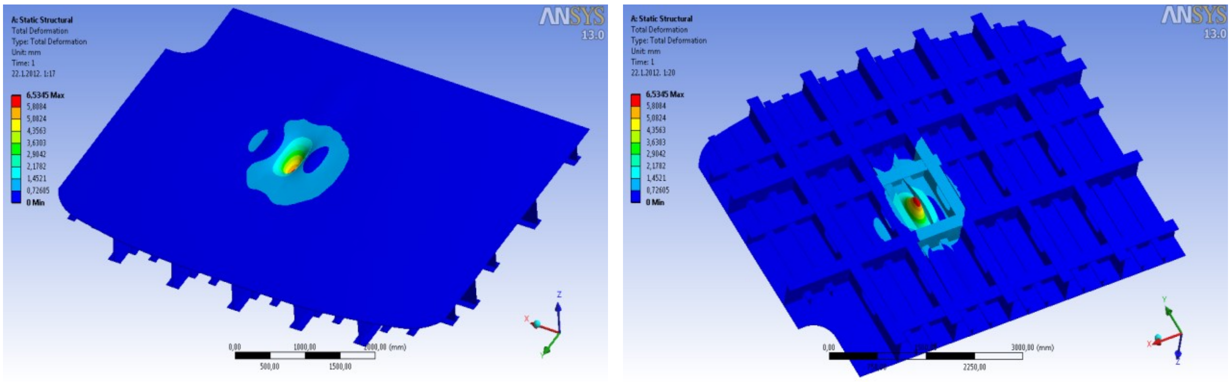

Figure 17.Deflection due to landing slink

It can be notice that maximum deflection is reached in the middle of the plate, approx. 6.5 mm, similar results being obtained in the theoretical calculations, approximately 7 mm deflection, in the middle of the plate.

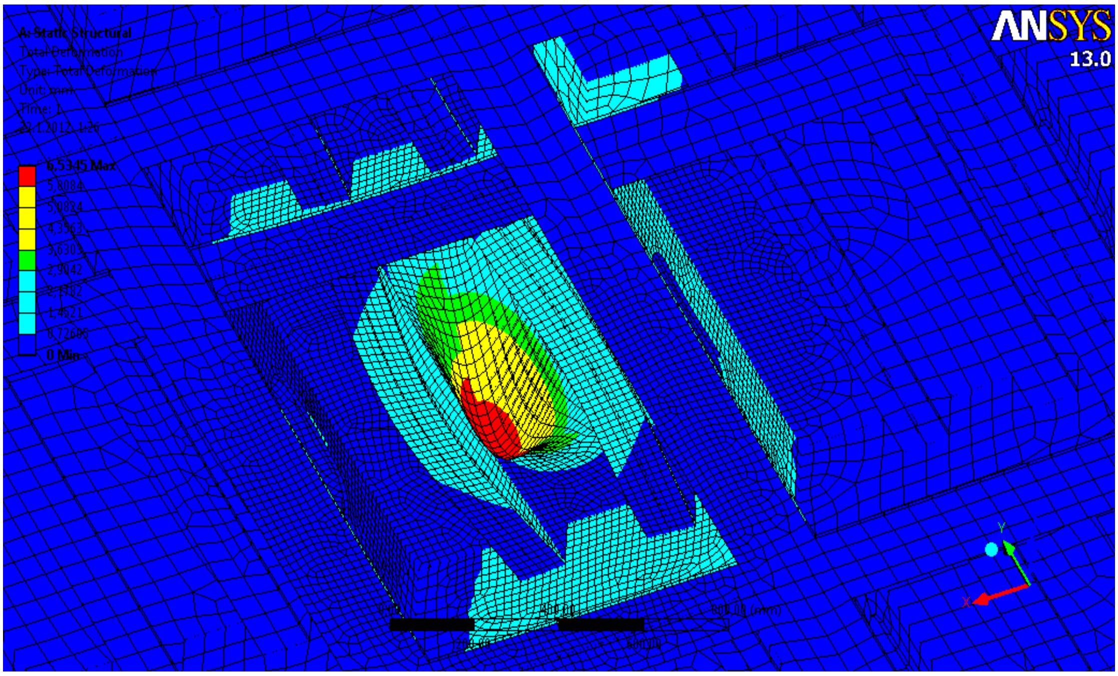

Figure 18.Local Deflection

Due to the fin accuracy mesh used around the loading region it can be notice how accurately the deflection slope is represented, see fig.18, and how the stresses are spreading around to loading area, and locally transferring the moments to the secondary longitudinal members. Further it can be also noticed that the transvers primary members are also contributing, from both sides approximately symmetrical, but the interesting part is the primary longitudinal girder (the one from the right of fig.18) which is contributing more than the one symmetrical to him, this phenomena probably is due to the structural instability, the girder from the right is the center girder of the structure, which means that when loading is applied its right girder tries to keep the structural stability, but loading being locally relatively high is “pulling” the center girder after it. The same thing could happen if the loading would be on the right side of the center girder.

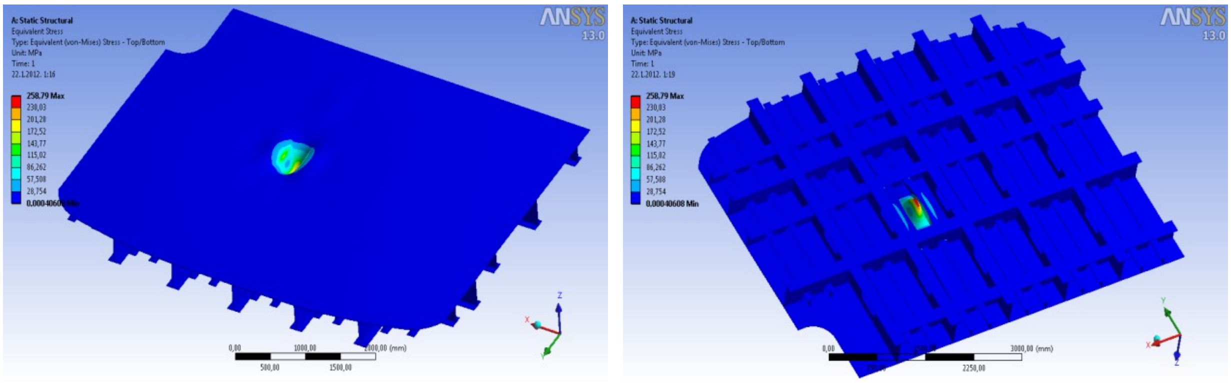

Figure 19.Von-Mises Stress field

Fig. 19-20 represents the Von-Mises stress field, upon which it can be notice that the maximum Von-Mises stress flow will be reached in the middle of the loading area, which is really high, the maximum stress reaching even 235 MPa in the middle of the plate reaching the yielding strength of the material (aluminum).

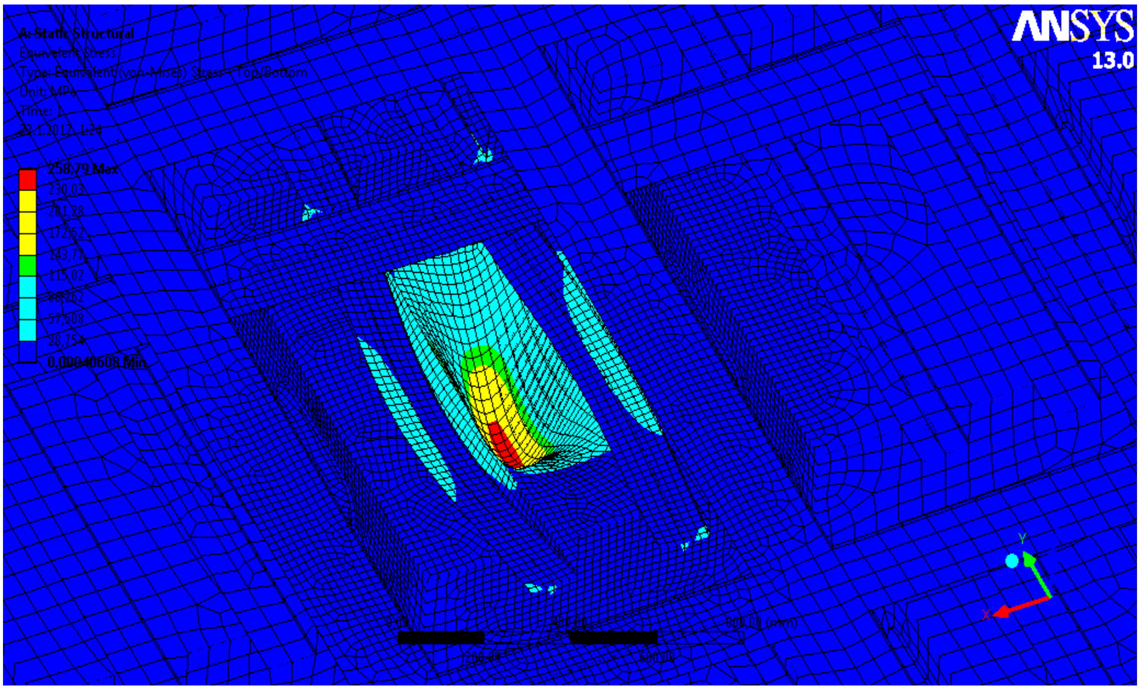

Figure 20.Von-Mises stress field distribution

Also in the normal stress case, see fig 21-22, is reaching really high stresses in the plate,

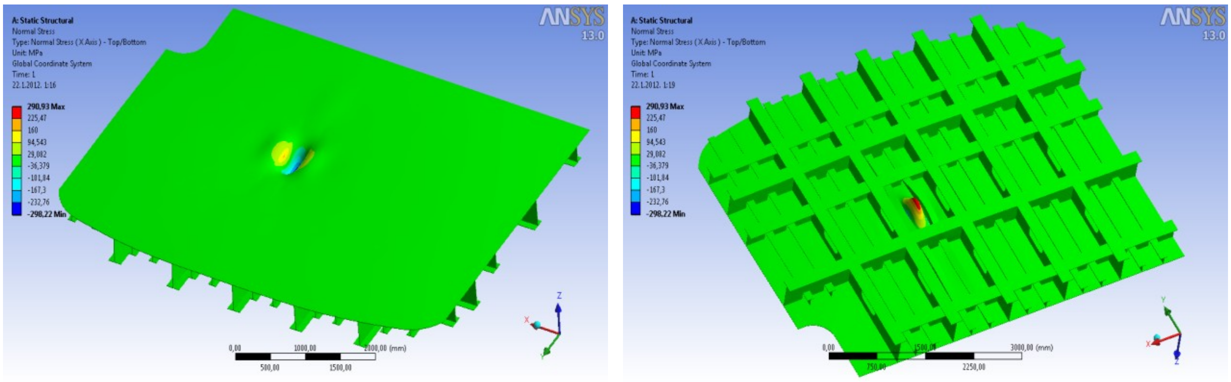

Figure 21.Normal stress field

approximately 290 MPa, in this case reaching the ultimate tensile strength of the material.

Going back to the theoretical assessment, the obtained stress are relatively equal, with the ones obtained in the FEM analysis, but it has to be remembered that this structure is not a certified landing area, and also this situation, 2.3 MPa loading in one small area is relatively impossible to happen, but to obtain a structural certification, this criteria has to be fulfilled.

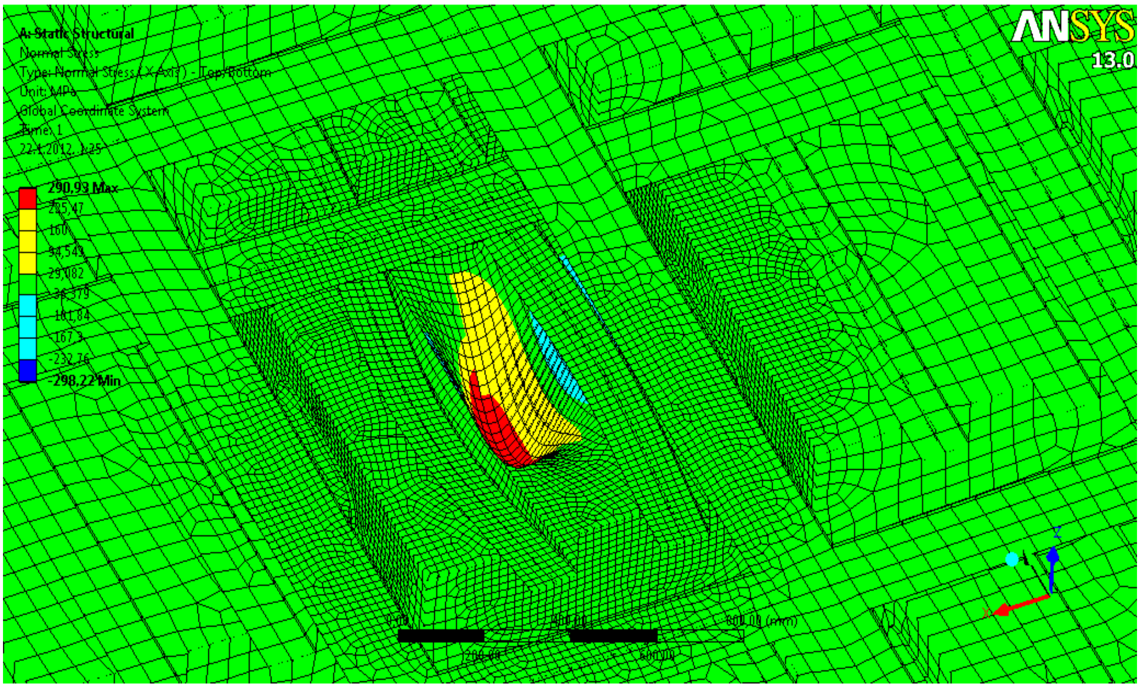

Figure 22.Normal stress field local distribution

The shear stress is reaching at the one quarter of the loading patch, see fig.23-24, due to

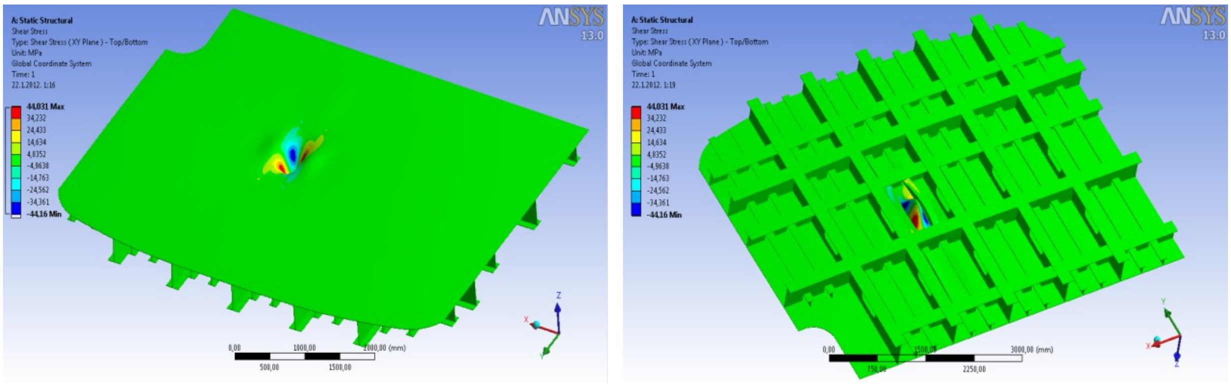

Figure 23.Shear stress distribution

shear force and twisting moment. As it was mentioned the maximum shear stress is reached at the edges of the loading, approximately 40 MPa, likewise the theoretical calculation, where it was nearly reaching 3 MPa. It can be also notice also some significant shear flow in the secondary longitudinal stiffeners, this being twisted due to the reaction from the loading patch edges.

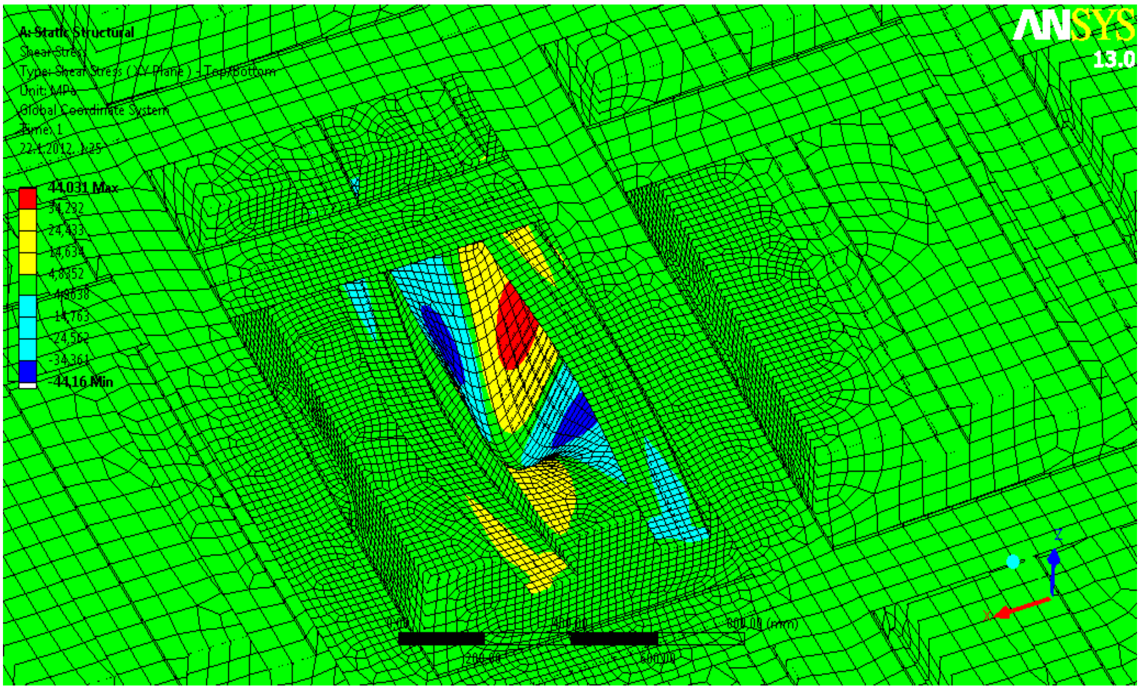

Figure 24.Shear stress field local distribution

It has been showed that designing and obtaining a certified landing area is relatively complicated, having a relatively stiffened structure, with 10 mm thickness, biggest unstiffened plate area being 1200x333, is not giving sufficient structural strength to ensure a helicopter emergency landing.

It has to be noted that this section wasn't mandatory, but in insufficiency of resources, examples (practical or theoretical) in design of certified landing areas, this analysis was useful in aiming experience and furthermore to accomplish in the best way possible the requirements of this research.

2.4. Determination of the geometrical constraints

2.4.1. Introduction

This chapter outlines geometrical requirements for the characteristics of helicopter landing areas on large yachts. As part of the verification of landing area compliance, it should be stated for each helicopter landing area the maximum size of helicopter in terms of D-value and the maximum take-off weight of the heaviest helicopter in terms of “t” value for which each landing area are certificated with regard to size and strength.

As already introduced in the second sub chapter, section 2.3, the geometrical constraints are the landing area design main points. They can be considered as the new helideck geometrical design boundaries.

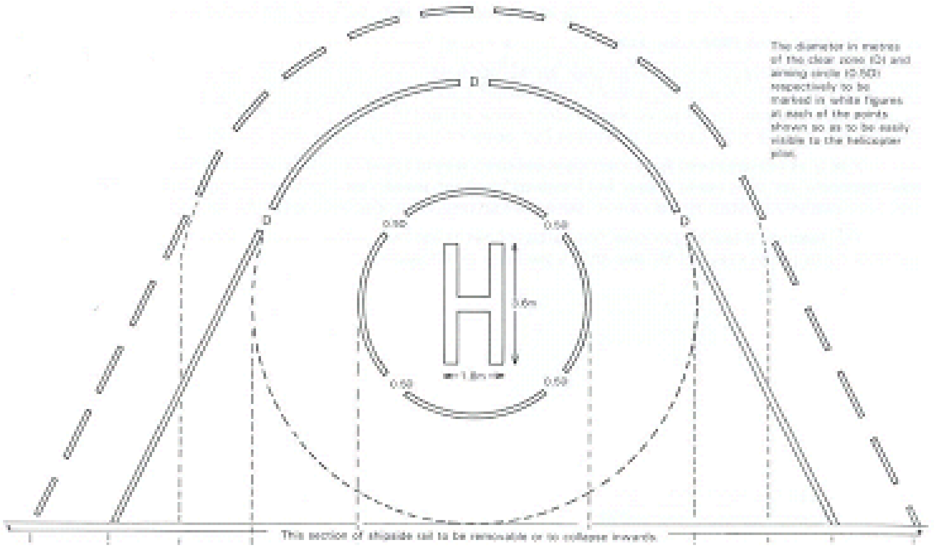

Figure 25.Landing area general geometrical considerations

The overview made in the related main chapter two, it can be undersigned that the helicopter, the landing area and they geometrical position on a yacht are directly connected to each other. Starting from the geometrical position, which offers the operational domain; continuing with the helicopter which was chosen in accordance to his operational domain and necessary, and finally getting the geometrical dimensions of the landing area. Therefore according to rules (MCA, LY2 code) the geometrical size of the helicopter is giving the geometrical constraints of the landing area. Hereby knowing the helicopter geometrical dimensions the landing area geometry, his operational surrounding boundaries, and also the landing area surface can be defined.

2.4.2. Helicopter Landing Area Design Considerations

2.4.2.1. Size of Landing Area (SLA)

In order to a helicopter may land, it is necessary to have a minimum geometrical D value. This D value is defining the minimum required length of the landing area; this value is given by the maximum geometrical length measured by the helicopter (see chapter 2, subsection 2.4), according to the chosen, Eurocopter Colibri EC 120, technical description, the D value (maximum overall length of this helicopter) is 11520 mm.

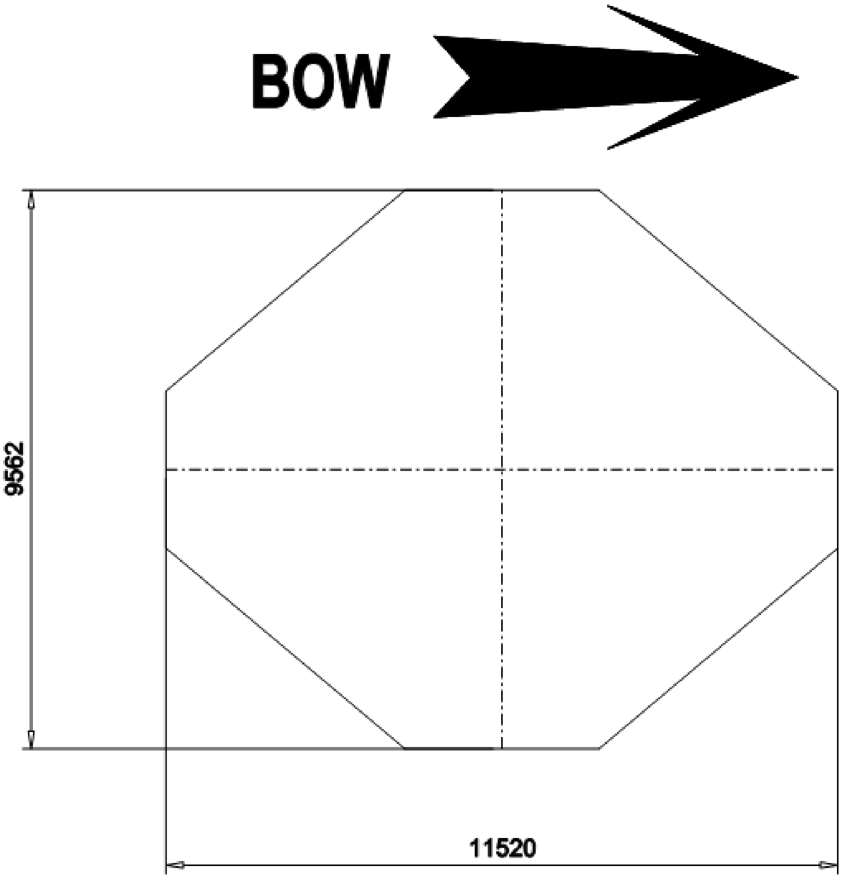

Figure 26.Obtained landing area geometrical size

According to the MCA LY2 attendant (see Annex 1), in order to a helicopter may land, with a single main rotor helicopter or side-by-side twin main rotor helicopter, have to be of sufficient size to contain an area within which can be drawn a circle of diameter not less than 1.0 times D of the largest helicopter the helideck is intended to serve, where D is the largest dimension of the helicopter when the rotors are turning. In other hand the width of the landing area may offer some flexibility to designers of new helidecks on charters, due to the space restriction, and this dimension shell be taken at least 83% from the overall D value, which will give a total minimum width requested for this application of 9562 mm.

Therefore fig.26 shows the effective overall minimum dimensions needed, according to the LY2 attendant, for a Colibri EC120 helicopter to be able to land.

2.4.2.2. *Obstacle Protected Surfaces (OPS)*

Another important issue is due to the touchdown heading of the helicopter which is limited to the an angular distance subtended by the 1D arc headings, minus 15 degrees at each end of the arc, the result is shown in fig.27 below.

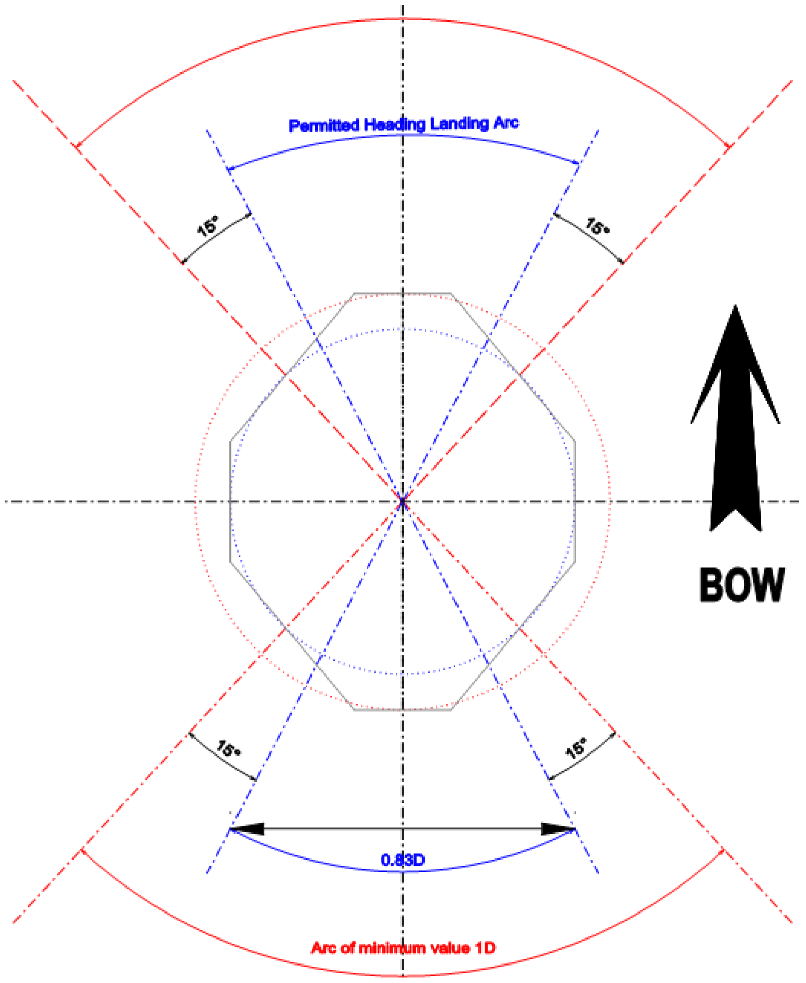

Figure 27.OPS requirements for the obtained landing area

In such arrangements of landing areas, the vessel will need to be maneuvered to ensure that the relative wind is appropriate to the direction of the helicopter touchdown heading. The touchdown heading of the helicopter is limited to the angular distance subtended by the 1D arc headings, minus 15 degrees at each end of the arc.

According to fig.26, which constitute the main landing area surface geometrical requirements given by the MCA rules L2Y attendant presented in Annex 1, sub-section 3, paragraph 3.1; helicopters may land and effectuate operation only if the minimum geometrical requirements are fulfilled according to the above fig.27 presentation.

This requirement is due to the obstacle free sector consideration, which allows a free and safety operation of the helicopter around the landing area. For this it's requested an obstacle free sector around any point around the 1D periphery, which should be not less than a sector of 210°. In this arc sector should not be included any obstruction structures, even if they obstruct it the height of this structures shell not be higher than 250 mm, this area being intended to serve only for helicopter operational space.

From any point on the periphery of the above mentioned D circle an obstacle-free approach and take-off sector should be provided which totally encompasses the safe landing area (and D circle) and which extends over a sector of at least 210°. Within this sector, from the periphery of the landing area and out to a distance that will allow for an unobstructed departure path appropriate to the helicopter that the landing area is intended to serve, only the following items may exceed the height of the landing area, but should not do so by more than 250 millimeters:

- The guttering (associated with the requirements in paragraph 4.2 of MCA rules,MY2);
- The lighting required by Section 4;
- The foam monitors;
- Those handrails and other items associated with the landing areas which are incapable of complete retraction or lowering for helicopter operations.

The bisector of the 210° obstacle free sector (OFS) should normally pass through the center of the D circle. The sector may be 'swung' by up to 15° as shown in fig.28, below. Acceptance of the 'swung' criteria will normally only be applicable to existing vessels.

If, for an existing vessel, the 210° obstacle free sector is swung, then it would be normal practice to swing the 180° falling 5:1 gradient by a corresponding amount to indicate, and align with, the swung OFS.

2.4.2.3. Limited Obstacle Sector (LOS)

The diagram at fig.28 shows the extent of the two segments of the 150° Limited Obstacle Sector (LOS) and how these are measured from the center of the (imaginary) 'D' Circle and from the perimeter of the safe landing area (SLA). This diagram assumes, since helicopter landing areas are designed to the minimum requirement of accommodating a 1 ‘D’ Circle, that the ‘D’ Circle perimeter and SLA perimeter are coincidental. No objects above 0.05D are permitted in the first (hatched area in fig.28) segment of the LOS.

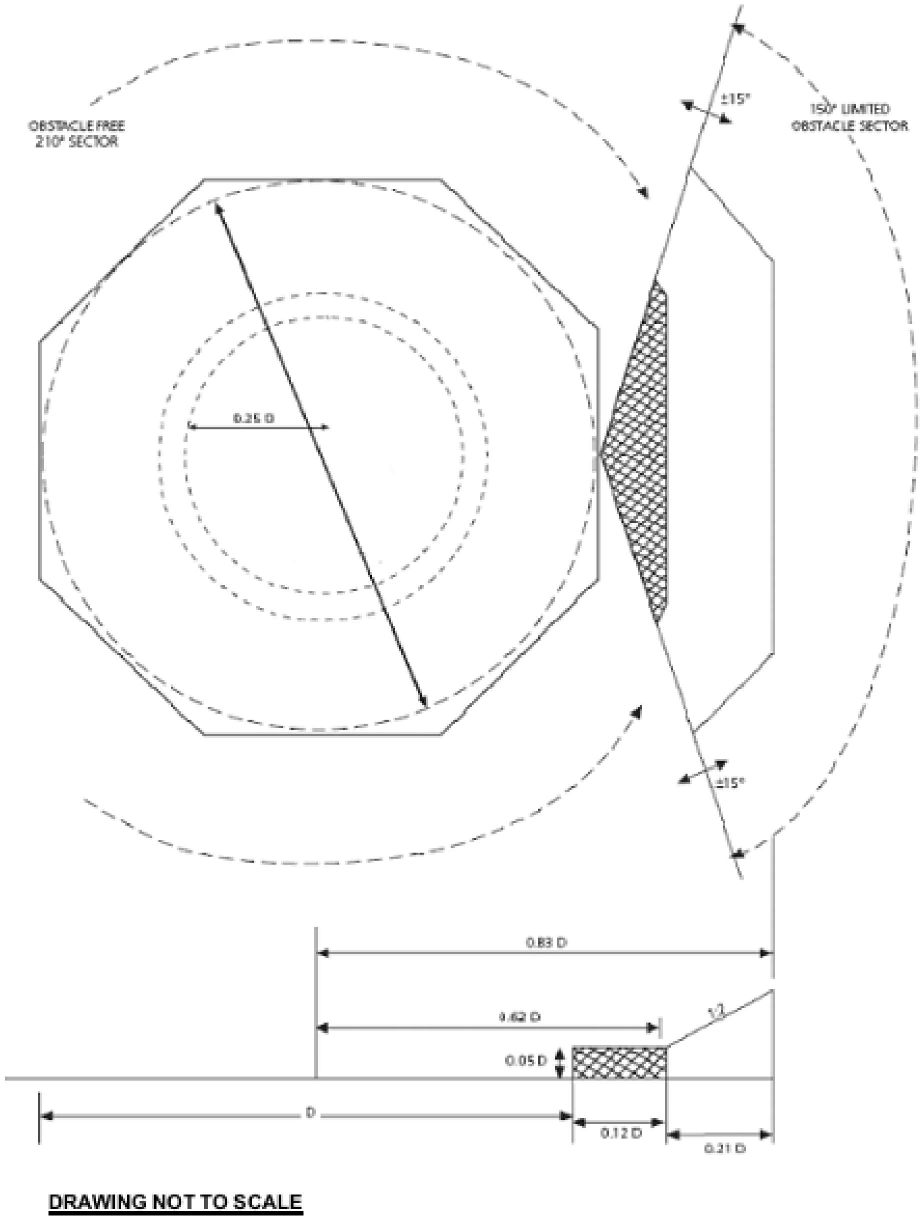

Figure 28.Obstacle Limitation showing position of Aiming Circle

The first segment extends out to 0.62D from the center of the ‘D’ Circle or 0.12D from the SLA perimeter marking. The second segment of the LOS, in which no obstacles are permitted within a rising 1:2 slope from the upper surface of the first segment, extends out to 0.83D from the center of the ‘D’ Circle, or a further 0.21D from the edge of the first segment of the LOS.

The exact point of origin of the LOS is assumed to be at the periphery of the ‘D’ Circle. According to the presented restriction the landing area will be design as show in fig.29.

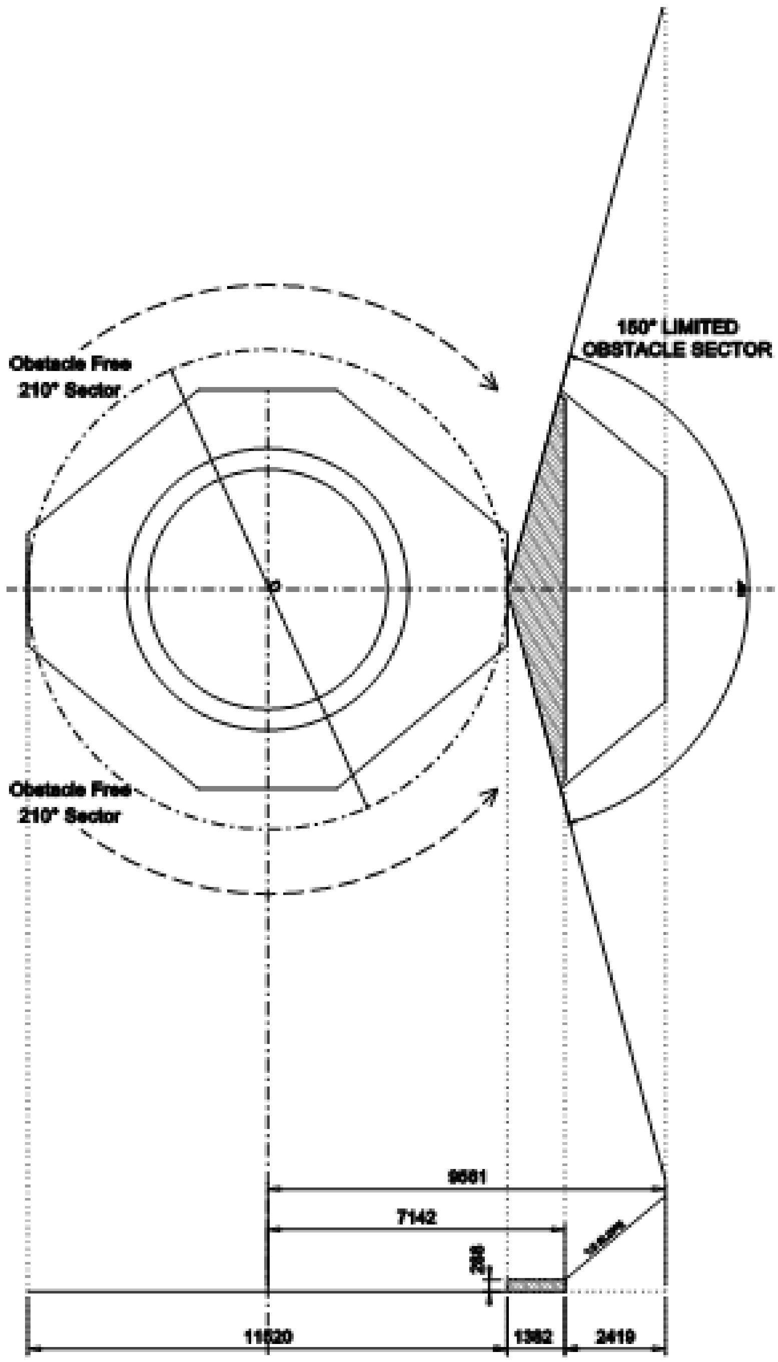

Figure 29.LOS consideration for the designed landing area

Some helicopter landing areas are able to accommodate a SLA which covers a larger area than the declared ‘D’ value; a simple example being a rectangular deck with the minor dimension able to contain the ‘D’ Circle. In such cases it is important to ensure that the origin of the LOS (and OFS) is at the SLA perimeter as marked by the perimeter line. Any SLA perimeter should guarantee the obstacle protection afforded by both segments of the LOS. The respective measurements of 0.12D from the SLA perimeter line, plus a further 0.21D are to be applied. On these larger decks there is thus some flexibility in deciding the position of the perimeter line and SLA in order to meet the LOS requirements and when considering the position and height of fixed obstacles. Separating the origin of the LOS from the perimeter of the 'D' Circle in Figure 1 and moving it to the right of the page will demonstrate how this might apply on a rectangular SLA.

The extent of the LOS segments will, in all cases, be lines parallel to the SLA perimeter line and follow the boundaries of the SLA perimeter (see Figure 1 above). Only in cases where the SLA perimeter is circular will the extent be in the form of arcs to the 'D' circle.

However, taking the example of an octagonal SLA as drawn at Figure 1, it would be possible to replace the angled corners of the two LOS segments with arcs of 0.12D and 0.33D centered on the two adjacent corners of the SLA; thus cutting off the angled corners of the LOS segments. If these arcs are applied they should not extend beyond the two corners of each LOS segment so that minimum clearances of 0.12D and 0.33D from the corners of the SLA are maintained. Similar geometric construction may be made to a square or rectangular SLA but care should be taken to ensure that the LOS protected surfaces minima can be satisfied from all points on the SLA perimeter.

2.4.2.4. Obstacle Free Areas (OFA)

Whilst application of the criteria previous paragraph, above will ensure that no unacceptable obstructions exist above the helicopter landing area level over the whole 210° sector, it is necessary to consider the possibility of helicopter loss of height due to power unit failure during the latter stages of the approach or early stages of take-off.

Accordingly, a clear zone should be provided below landing area level on all helicopter landing areas. This falling 5:1 protected surface should be provided over at least 180° and ideally it should cover the whole of the 210° OFS, with an origin at the center of the 'D' Circle, and extending outwards to a distance that will allow for a safe clearance from obstacles below the landing area in the event of an engine failure for the type of helicopter that the landing area is intended to serve (see Figure 30). All objects that are underneath anticipated final approach paths should be assessed.

Research completed in 1999 demonstrated that, following a single engine failure in a twin engine helicopter after take-off decision point, and assuming avoidance of the deck edge, the resulting trajectory will carry the helicopter clear of an obstruction in the range 2:1 to 3:1. It is therefore only necessary for operators of multi-engine helicopters operated in performance classes one or two (as defined in ICAO Annex 6 Volume 3) to account for performance in relation to specified 5:1 falling gradient where infringements occur to a falling 3:1 rather than a 5:1 slope.

For practical purposes, when a safety net is fitted, the falling obstacle limitation surface can be assumed to be defined from points on the outboard edge of the helicopter landing area perimeter safety netting supports (1.5 meters from deck edge). Minor infringements of the surface by foam monitor platforms or access/escape routes may be accepted only if they are essential to the safe operation of the helicopter landing area but these infringements may also attract landing area availability restrictions.

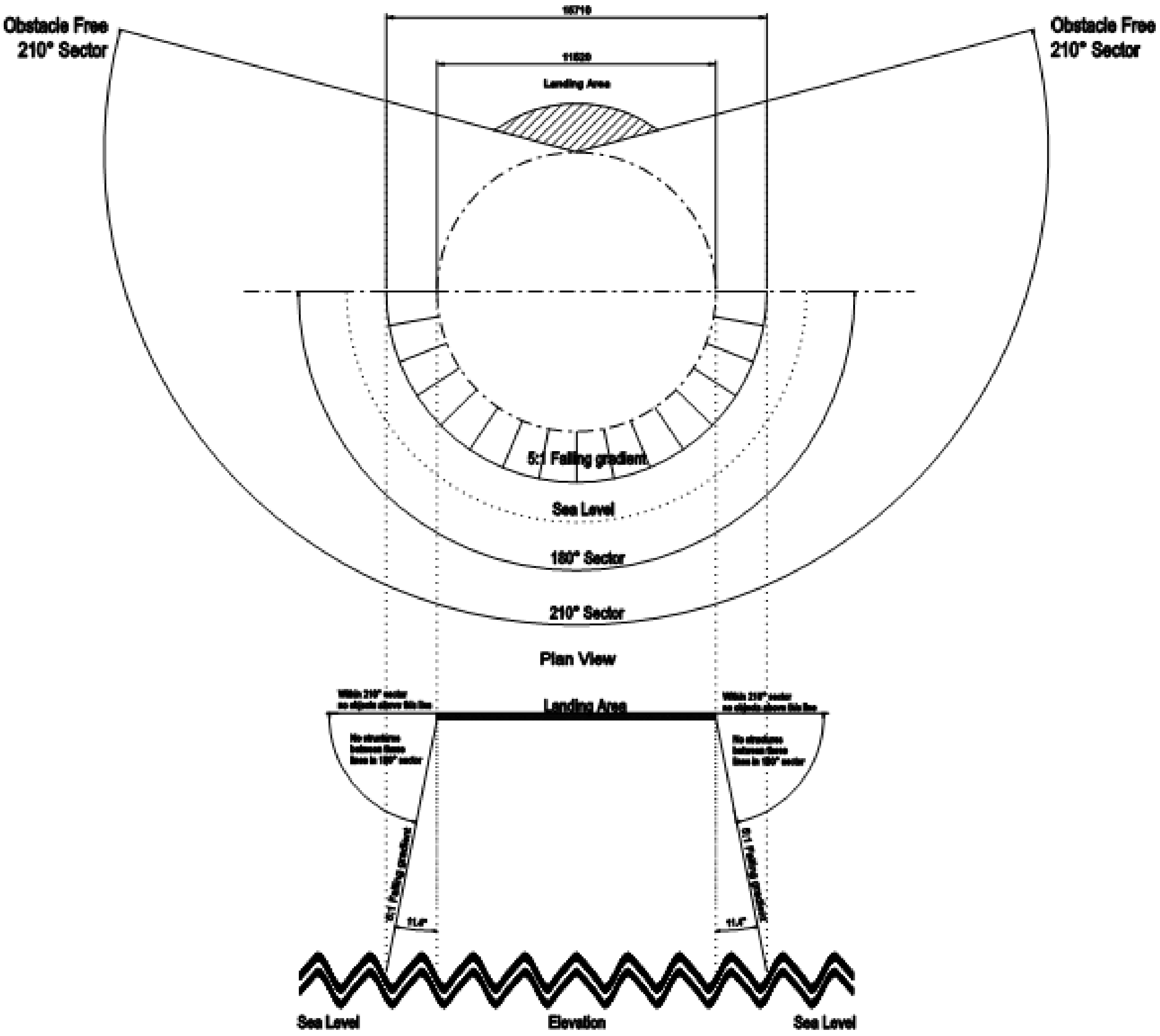

Figure 30.OFA consideration for the designed landing area

2.4.3. Other Design Considerations

2.4.3.1. Drainage system

This subsection outlines actually a part of the final modeling assessment, but his function and implementation in the landing area structure it will influence the final result of the design. Hereby, any helicopter landing areas should be cambered to a maximum gradient of 1:100. Which means that the landing area shell have a minimum inclination in such a way that any spillage of fuel, or water shell not remain on the surface of the landing area, which could influence a safety operation of the helicopter. Hereby the real geometrical design consideration will be the inclination of the landing area and not the drainage system. The cambering of the helicopter landing area surface shell be done in such a way that no distortion due to, for example, loads from a helicopter at rest should not modify the landing area drainage system to the extent of allowing spilled fuel to remain on the deck. A guttering system has to be provided around the perimeter, to prevent spilled fuel from falling on the other parts of the vessel, and to conduct the spillage to an appropriate drainage system.

The capacity of the drainage system should be sufficient to contain the maximum likely spillage of fuel on the deck. The calculation of the amount of spillage to be contained should be based on an analysis of helicopter type, fuel capacity, typical fuel loads and uplifts. The design of the drainage system should preclude blockage by debris. The helicopter landing area should be properly sealed so that spillage will only route into the drainage system.

2.4.3.2. Access Points

Definition of the access point through which the landing area may be accessed it shell be defined in the early design stage of any new landing area. Access points are referring in the first case to the helicopter, but more directly to passengers, is strictly important because it is necessary to ensure that during embarking and disembarking passengers will not be required to pass around the helicopter tail rotor, or under the front of the main rotor of those helicopters with a low profile rotor, should a 'rotors-running turn-round' be conducted.

Access points are defined with respect to the information related to the geometrical position of the landing area on the vessel. As it was already define in the previous sections, the landing area will be positioned on the sundeck, which general arrangement was also highlighted previously. Considering all this factors, the only access point, will be in the longitudinal direction of the vessel, direction of the bow.

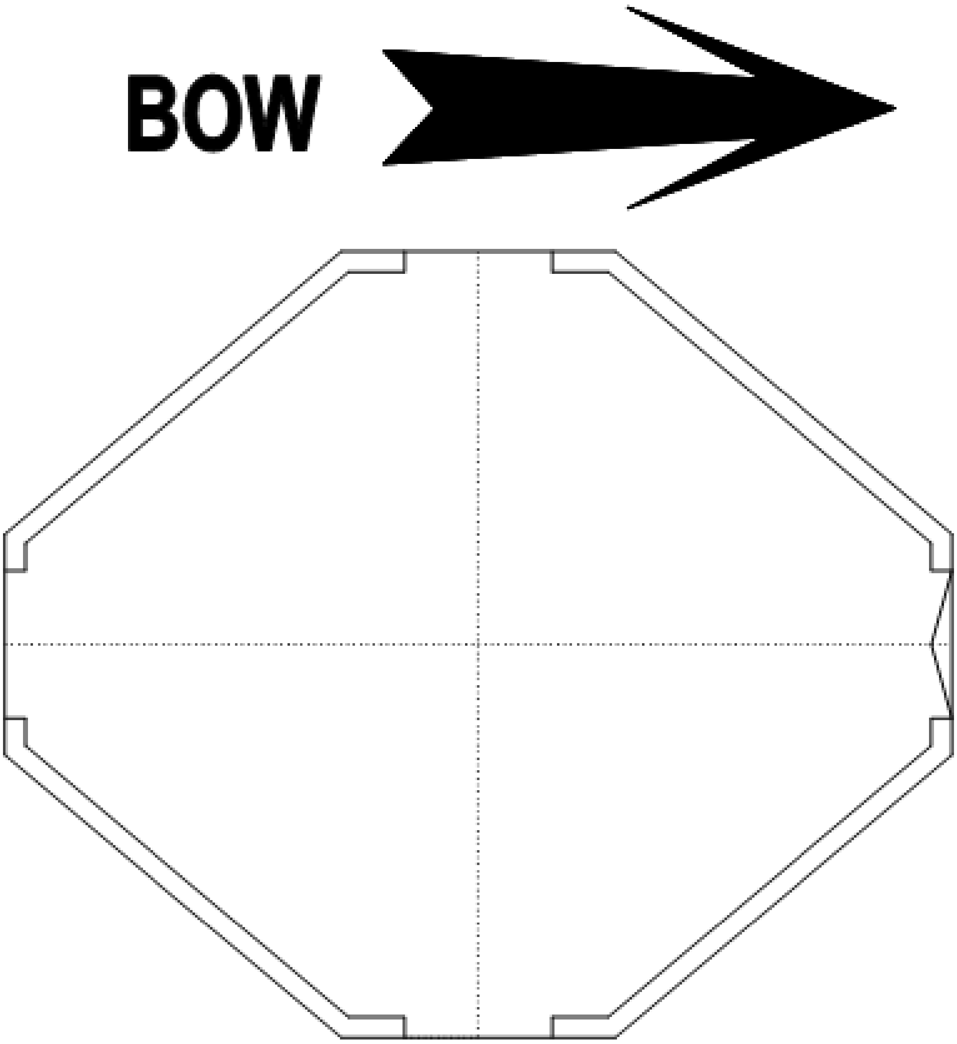

Figure 31.Landing area access points

Fig.31 highlights the landing area access points, thru which it can be identified one main access in direction of the vessels bow. According to the requirements of LY2 attendant, it should be considered minimum two access/egress routes to the helicopter landing area. The arrangements should be optimized to ensure that, in the event of an accident or incident on the helicopter landing area, personnel will be able to escape upwind of the landing area. Adequacy of the emergency escape arrangements from the helicopter landing area is also included as showed in fig.31, escape and rescue from the vessel, in three different points.

3. PRELIMINARY MODELING OF THE LANDING AREA

3.1. Aesthetic impact on the yacht

3.1.1. Introduction

Aesthetic is the main key of this research's design stage, which is also related directly or indirectly to all of the stages of the research. Hereby the aesthetical impact shell be considered locally, related to the landing area, but also globally, on board the vessel.

To approach as better is possible the aesthetic property, the task has to be approached initially from the information that are offered by the given vessel. As it has been already highlighted in the previous chapters, the landing area will be implemented on the sundeck of the vessel, which means that the solution has to be developed using al the known information related to the sundeck and its surrounding components. First of all the geometric size of the outside part of the sundeck it can be noticed thought fig.32 that its size is relatively small compared with the landing area obtained following the geometrical constraints of the LY2 rules. Hereby the proposed solution, as it was already introduced in the 2nd Chapter of this research, is to implement the new structure inside the structure of the sundeck.

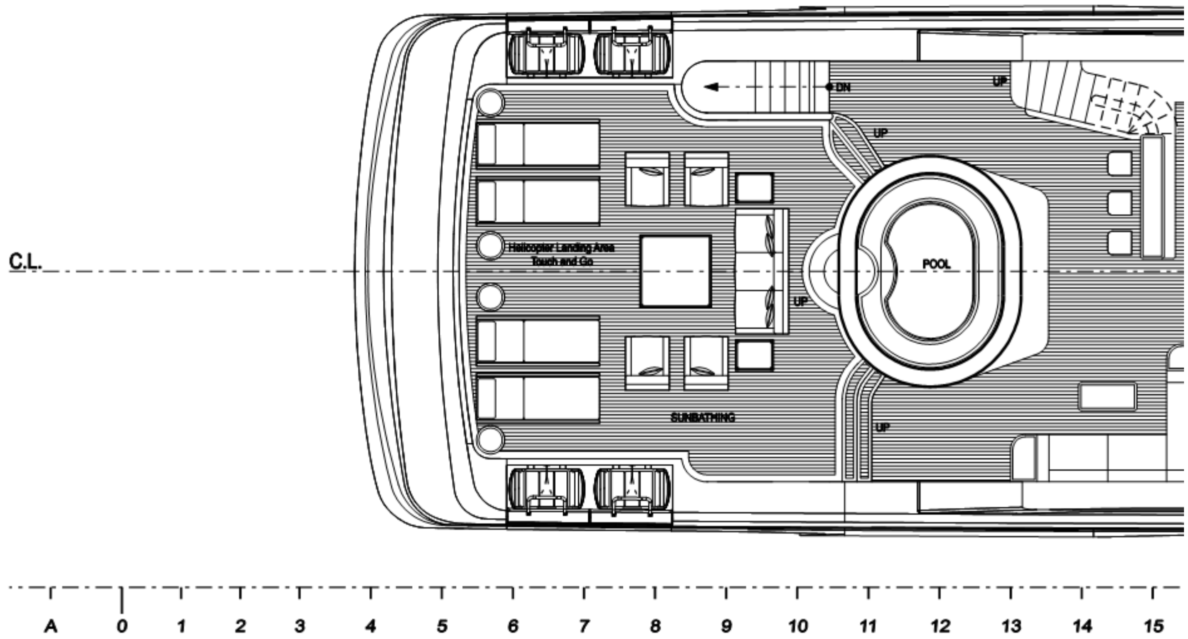

Figure 32.Initial vessels, weather deck

Therefore, the landing area has to be made foldable, and the sundecks general arrangement and structural scantling has to be modified.

3.1.2. Sundeck aesthetics

3.3.2.1. Sundeck general arrangement

As it was already discussed above the sundeck general arrangement has to be modified. Therefore as it can be seen on fig.33, the stairs which were making the connection with the upper deck were removed, and it will be placed somewhere near the rear of the sundeck.

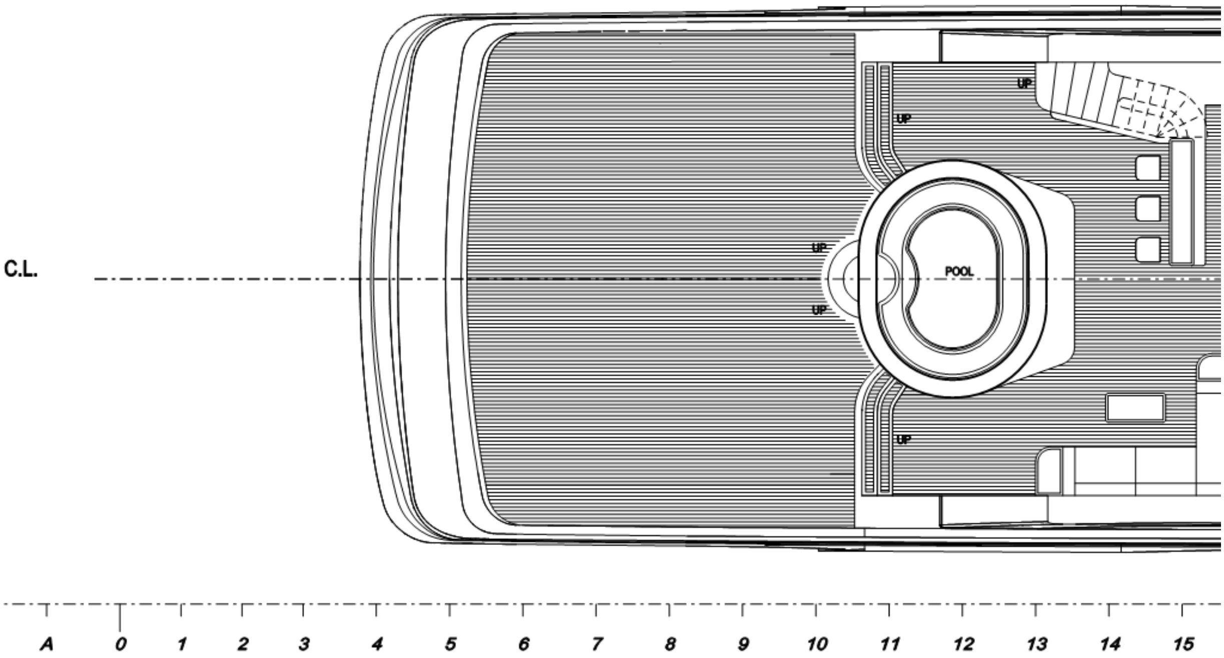

Figure 33.New sundeck preliminary general arrangement

Now, the Jacuzzi could be kept, but unfortunately will influence the access point to the landing area, therefore the Jacuzzi for now on will be removed, any further research for a new position can be done, in function of the request of the owner.

3.3.2.2. Sundeck structural scantling

2D modeling

First of all the geometrical overall length of sundeck, above the Jacuzzi has to be increased, fig.34 shows the modification made upon the sundeck structure.

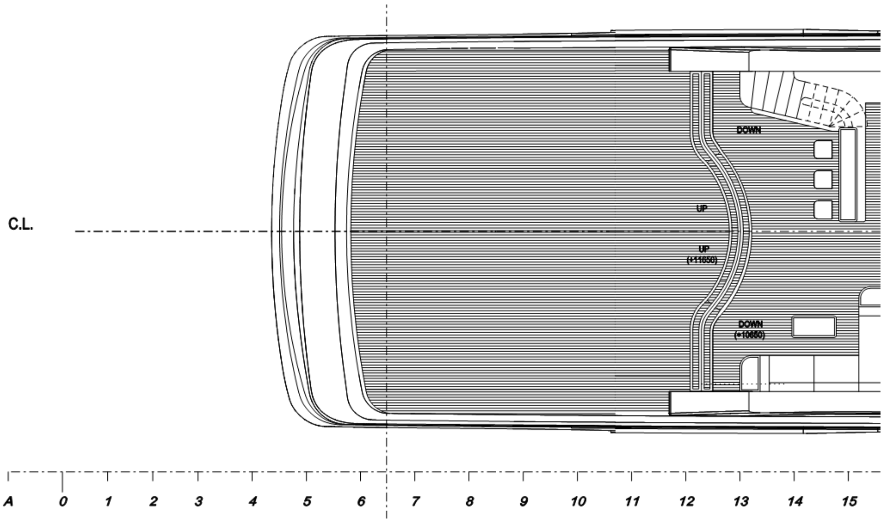

Figure 34.New Sundeck general arrangement

In order to be able to implement the helideck inside the sundeck structure the rear part of the sundeck will be cut, the vertical axis representing the cutting position, showed in the above figure. This cut, will allow the rear part of the sundeck to open, and make a translational motion, following the horizontal axis; more details related to this it will be discussed in the next chapter.

The next step is to optimize the existing scantling of the sundeck in order to fit the landing area inside. Fig.35 shows how initially the scantling looks. It can be notice that the height it relatively big, knowing that inside it has to be implemented the helideck with all his foldable mechanism.

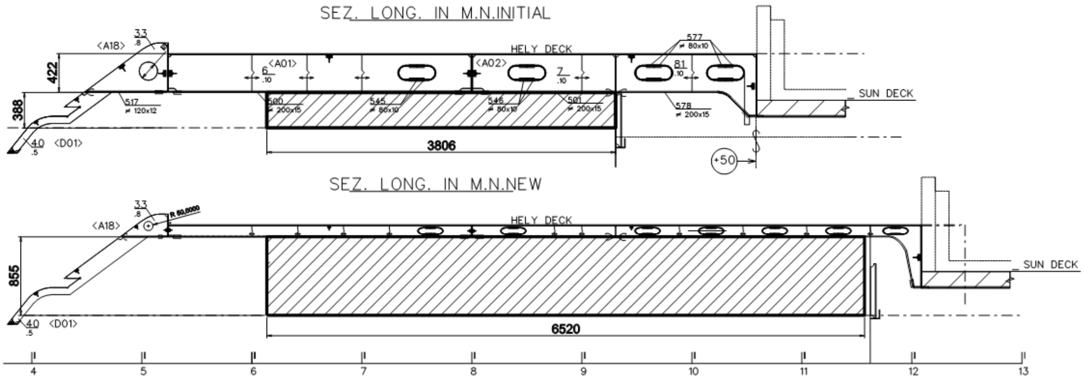

Figure 35.Initial/New Sundeck structural optimization

The hatched square in fig.35 (Initial, first drawing) represents the future “housing” of the helideck, which size it relatively small, compared to the required landing area size for Eurocopter EC 120. In order to increase this hatched area, the optimization has to be done by modifying the position of the roof of the upper deck (line under the hatched area), and by optimizing the height of the decks structure profiles.

The optimization of the structure has been done using a small excel spread sheet, through witch a minimum size were choose for the profiles in such a way to fulfil the requirements of the structural rules used by the company. The roof of the upper deck was also moved a bit lower and the vertical wall (represent by the beam on the left end of the hatched area) of the lower decks housing was also moved. Therefore, the landing area "housing" was significantly increased, offering enough space to fit in the helideck.

3D modeling

This small sub-section serves to highlight the structural scantling of the new sundeck, see fig.36-37. The virtual model was designed in Solidworks commercial software.

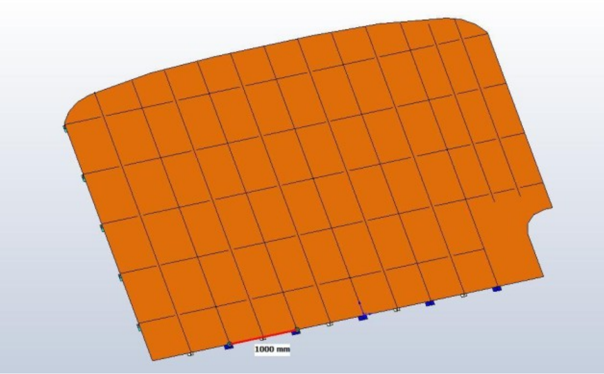

Figure 36.Longitudinal primary members spacing

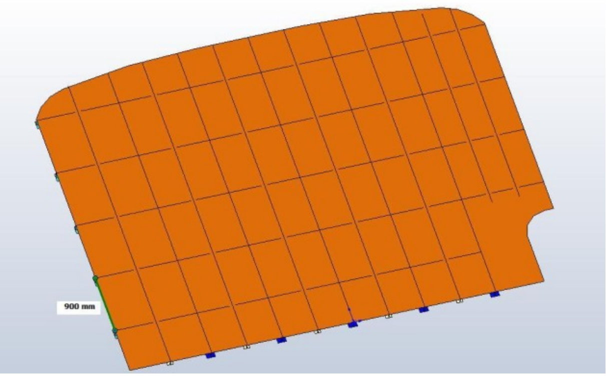

Figure 37. Transvers members spacing

In fig.36 it can be notice that the primary longitudinal members are equally spaced, at 1000 mm. Furthermore, transvers members are equally distributed on 900 mm spacing see fig.37.

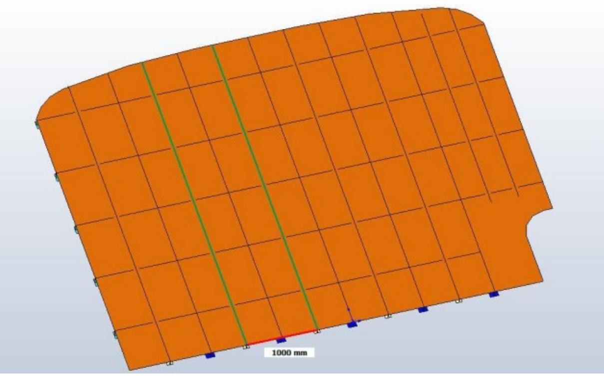

Figure 38.Longitudinal secondary members spacing

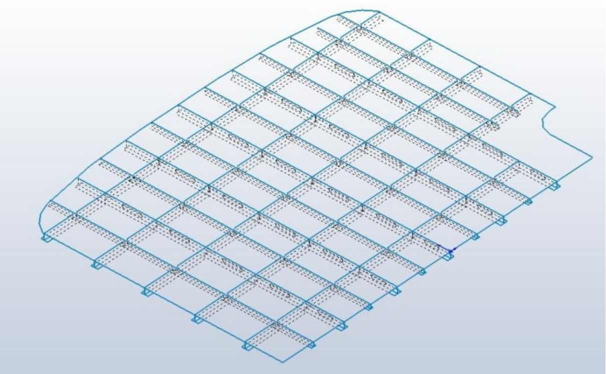

Figure 39. Virtual model general isometric view

The secondary longitudinal members being as well equally spaced, on 1000 mm each, see fig.38. It can be also notice from fig.40 that the primary longitudinal girders are sustaining the transvers members, they being welded to the girders. Furthermore the secondary members being sustained by the transvers members, likewise they length is spreading all through the deck area without any obstruction.

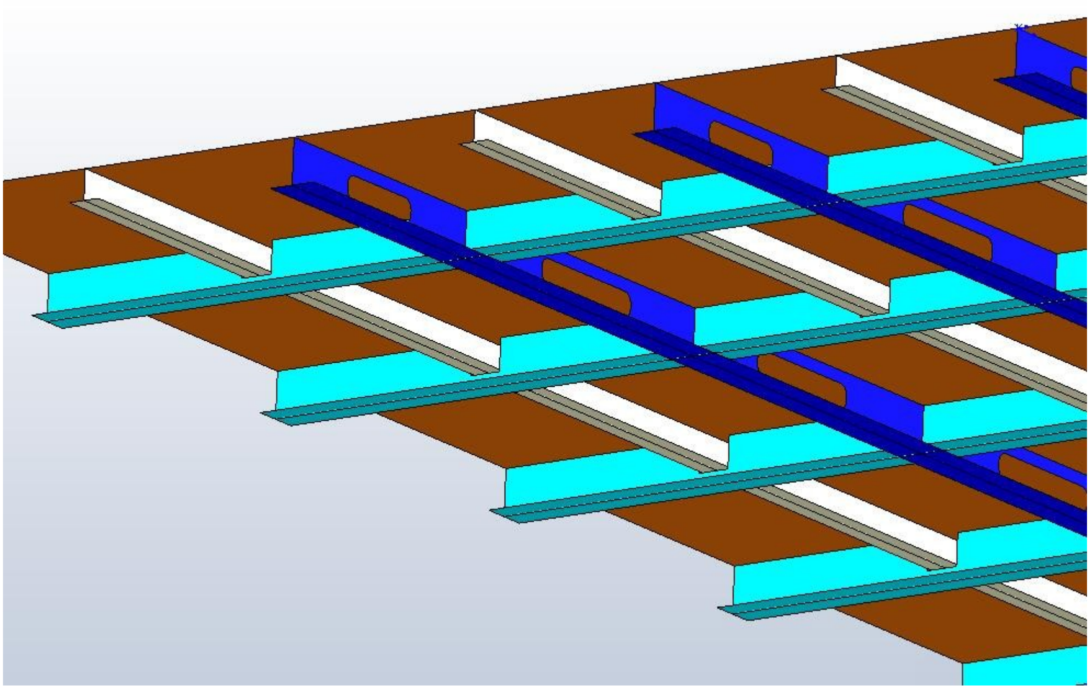

Figure 40.Virtual model scantling

As it was mentioned it the previous sub-section, the height of the longitudinal girders was reduced to 120 mm, like the transvers members, the secondary members of the longitudinal being reduced to 80 mm. Also the thickness of the upper plate was keep the same like in the initial sundeck case, 10 mm.

It has being showed that the new sundeck scantling was optimized, due to the space required, for the new helideck “housing”, and for the new possible loading that could damage the structural strength of the sundeck. The new sundeck structure was also optimized in such a way to be able to carry distributed pressure all around its surface, its only “barring” capability reducing to a simple weather deck. The minimum structural requirements for weather decks is 450 kg/m^2, furthermore in table 5, is estimated in more detail this requirement.

Table 5. Weather decks structural design considerations.

L	B	A	Pr	Pra	Phr	Pht	Ph
m	m	m2	kg/m2	N/m2	N/m2	MPa	MPa
4.71	6.31	29.74	450	4414.5	131281.202	0.131	2.31

Where,

L - Weather deck length;

B - Weather deck breath;

A - Weather deck area;

Pra – minimum requested force/unit area;

Pht – the minimum requested pressure/area;

Ph – helicopter pressure, induced during worst landing.

It can be seen in table 5, that the minimum requested design pressure for the weather deck area is relatively small, this notice being made by comparing the minimum design pressure required for the landing area. It has been showed in the previous chapter, Initial sundeck section, that the helicopter during his worst landing condition, with 2,3 MPa can induce really high structural instability, the local maximum stresses due to really small contact area, 300x64 mm, locally even the ultimate tensile strength of the material, approximately 270 MPa, can be reached. But remember that analysis was considered locally, on the mentioned small area, in this case distributing the requested 0,13 MPa on the hole sundeck, is unlike that it will produce any structural instability problems. Anyhow, has to be note that this is just a remark, before a final design stage, registration officers can give advices in order to avoid any structural problems.

Furthermore the new helideck aesthetic is discussed, in order to implement it in the just created sundeck housing.

3.1.3. Helideck aesthetics

Now, as it was already discussed earlier in this chapter, the helideck will foldable. In order to make it foldable, it has to be divided on smaller parts. Knowing the area which is defining the available housing space for the helideck (see fig.), this area is defining helideck main part size (hatched area, part number 0).

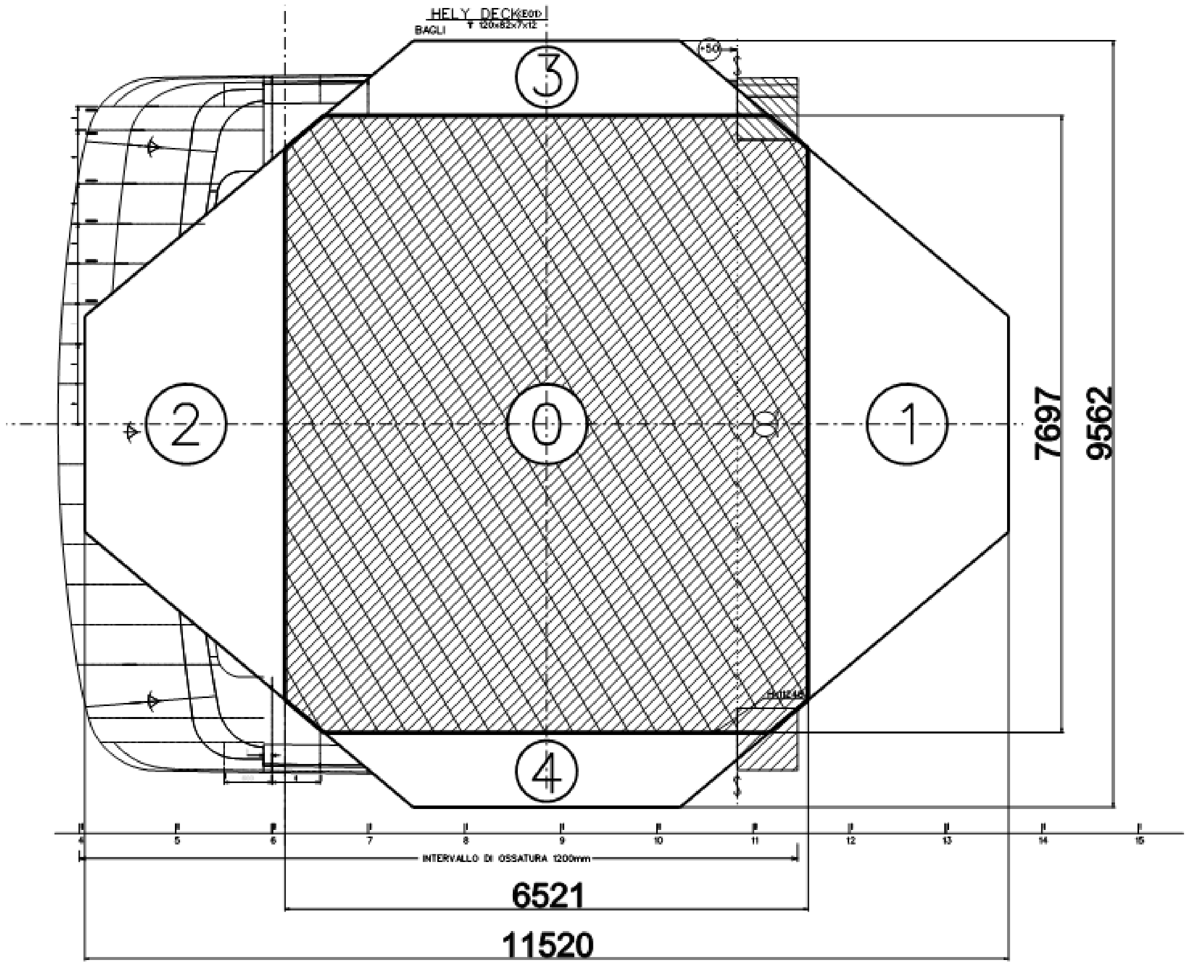

Figure 41.Sundeck top view; helideck foldable parts

In fig.41 the hatched are represents the available place inside the structure of the sundeck, which defines the fix part of the foldable helideck. The rest 4 parts which are outside of the hatched area are representing the 4 foldable parts of the helideck, which were obtained just by mirror projection on the fix part, in such a way that during folding and unfolding the 4 movable parts will not interfere with each other.

3.2. Modeling of the landing area

4.2.1. Introduction

Maybe the most important part of the research, all the preliminary research of the work made until this stage it can be seen in this stage. But without all the steps made before the design stage it couldn't be possible.

A preliminary 2D design presentation was made already in chapter 2 of this research – which was based just on constraints given by MCA rules – based on this it can be performed a small preliminary structural assessment. A further detailed 3D design it could be made just after more detailed knowledge about the structural properties of the new structure.

In order to start a detailed design stage it's mandatory to study and define one really important criterion, a preliminary structural assessment. Which will define the helideck structure material, minimum plate thickness, and his minimum strength needed for a helideck on which safety offshore operation have to can be completed by a helicopter. The structural analysis it's based on the Lloyd's Register rulebook.

The information collected and description details made until this stage it's enough for a first preliminary design which can offer good results without taking in consideration any other criteria's just the ones presented until now.

Therefore, in the presented chapter will be given already a preliminary 3D design of the helideck, based on the rules (MCA LY2, CAA, LR and ABS), which will follow the research body in all of the stages of the research. The Siemens Nx. Software will be used in the preliminary 3D modeling stage.

4.2.2. Preliminary structural assessment

As already presented in the rule review chapter, the structural assessment it is based on Lloyd's Register rule book.

To get start a structural assessment it should be known more information related to the structure, but the geometry of the helideck and

To define this, from Lloyd's Register's rule book; Volume 4, Part 6, Chapter 5, Section 6-"Helicopter landing areas" was applied.

Minimum Plate thickness

This subsection is the first structural assessment step, which by nonlinear analysis defines indirectly the minimum scantling and further the minimum plate thickness, everything base on the loading induced by the helicopter during his operation on the landing area.

Hereby the first step is to read the predefined minimum plate thickness formula offered by the LR rule book.

$$t_p = \frac{\alpha * s}{1000 \ \overline{k_s}} \tag{4}$$

Where,

α = thickness coefficient obtained from fig. 42;
s = secondary stiffener spacing, s= 600 mm;
k_s = higher tensile factor;
Defined as:

$$k_s = \frac{235}{\sigma_s} \tag{5}$$

Where,
σ_s = specified minimum yield strength of the aluminum, σ_s = 180 N/mm2, due to welding.

$$\sigma_s = \frac{235}{180} = 1{,}3$$

Now, in order to obtain the minimum plate thickness according to Eq.4, the related parameters which are composing the related equation have to be obtained one by one. The first parameter its thickness coefficient, α, obtained from fig.42, but in order to obtain this coefficient according to fig.42, the thickness coefficient, α, have to be obtained from the fig through an interpolation between the v/s ratio, β_p.

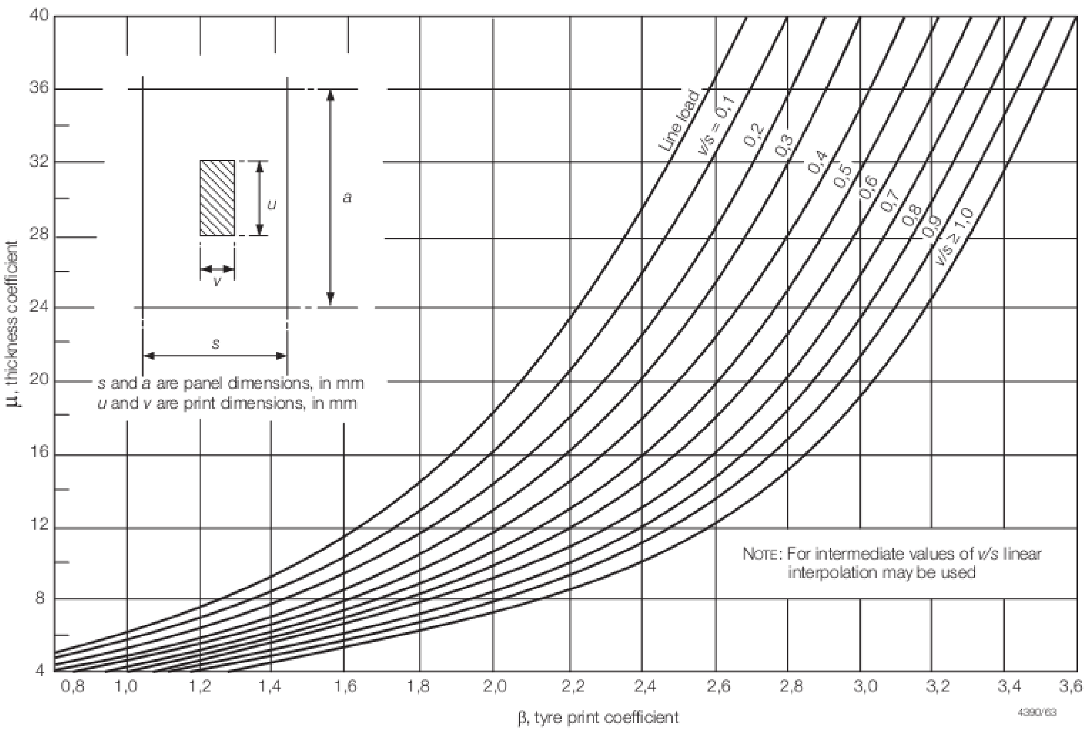

Figure 42.Tyre print chart

Starting with the mentioned ratio, where v, u are representing the print dimensions of the helicopter landing slink during worst emergency landing, presented in fig.42, v=64 mm and u=300 mm, giving a ratio of 0,1. Now knowing the first interpolated factor, the second one β_p, tyre print coefficient, being define as:

$$\beta_p = log_{10}\frac{P_1 * {k_s}^2}{s^2} * 10^7 \tag{6}$$

Where,

s = stiffener spacing, in mm;

The landing area plating is designed for the emergency landing case taking, defined by P_1 as:

$$P_1 = 2{,}5 * \varphi_1 * \varphi_2 * \varphi_3 * f * \gamma * P_w \tag{7}$$

Where,

- f = 1, 15 for landing decks over manned spaces, e.g. deckhouses, bridges, control rooms, etc.
- f= 1, 0 elsewhere, hereby f=1, 15, as already defined in the beginning of the research that the landing area will be placed on the sundeck.

P_h = the maximum all up weight of the helicopter, P_h = 1, 8 tones.

P_w = landing load, on the tyre print, in tones;

P_w it will be taken as P_h (for helicopters with single main rotor)

γ = a location factor given in Table 3

Table 6 Location factor, γ:

Location	γ
On the decks forming part of the hull girder: (a) within $0{,}4L_R$ amidships (b) At. the F.P. or A.P.	 0,71 Values for intermediate locations are to be 0,6 determined by interpolation
Elsewhere	0,6

Hereby according to Table 2 γ=0, 6.

Finishing with the emergency landing case definition, the only unknown factors are φ_1, φ_2, φ_3. Hereby φ_1 is defined as:

$$\varphi_1 = \frac{2v_1 + 1{,}1s}{u_1 + 1{,}1s} \tag{8}$$

To obtain the parameters which are defining φ_1, these have to go through a logical comparison with the main supports of the landing area plating, and the helicopters foot print components, these being defined as it follows:

$$v_1 = v, but\ \leq s \tag{9}$$

Hereby:

$$v_1 = v = 64\,mm\,, because\ \leq 600\,mm$$

The second component u_1 is defined by the next logical expression:

$$u_1 = u, but\ \leq a \tag{10}$$

Where,

a = is the longitudinally member support of the deck plating, a = 1200 mm

This will give:

$$u_1 = u = 300\,mm\,, because\ \leq 1200\,mm$$

These being concluded, the obtained values can be substituted in Eq. 5, and it will be obtained that:

$$\varphi_1 = \frac{2 * 64 + 1{,}1 * 600}{300 + 1{,}1 * 600} = 0{,}8$$

Further φ_2 is obtained, defined by three logical expressions as it follows:

$$\varphi_2 = 1\,for\ u \leq (a - s) \tag{11}$$

$$\varphi_2 = \frac{1}{1{,}3 - \frac{0{,}3}{s}(a-u)} \quad for\ a \geq u > (a-s) \tag{12}$$

$$\varphi_2 = \frac{2v_1 + 1{,}1s}{u_1 + 1{,}1s} \quad for\ a \geq u > (a-s) \tag{13}$$

The parameter are fulfilling the requirements of Eq. 11 , hereby, $\varphi_2=1$.

The last unknown component is φ_3 which can be calculated in the same logical comparison fashion, defined by:

$$\varphi_3 = 1\ for\ v < s \tag{14}$$

$$\varphi_3 = 0{,}6\ \frac{s}{v}\ + 0{,}4\ for\ 1{,}5 > \frac{v}{s} > 1{,}0 \tag{15}$$

$$\varphi_3 = 1{,}2\ \frac{s}{v}\quad for\ \frac{v}{s} \geq 1{,}5 \tag{16}$$

The requirements of Eq.14 are totally fulfilled and this gives the value for $\varphi_2=1$.

All the unknown parameters for the emergency landing weight where computed, hereby the obtained parameters can be substituted in Eq.7, which will give:

$$P_1 = 2{,}5 * 0{,}8 * 1 * 1 * 1{,}15 * 0{,}6 * 1{,}8 = 2{,}5\ tones$$

Knowing P_1, tyre print coefficient, β_p, can be computed from Eq.6:

$$\beta_p = log_{10} \frac{4{,}3 * (1{,}3)^2}{600^2} * 10^7 = 2{,}1$$

All this being computed, knowing the ratio v/s=1, and just obtained tyre print coefficient, β_p, interpolating the two coefficients, using fig.42, thickness coefficient, will became, α =24.

Hereby, all the necessary parameter for minimum plate thickness being computed, substituting them in Eq. 4:

$$t_p = \frac{24 * 600}{1000\ \overline{1{,}3}} = 13\ mm \tag{17}$$

The minimum plate thickness is relatively high; hereby a small weight analysis is carried out in order to check the weight of the landing area. But first a preliminary 3D structural design shall be done.

4.2.3. Preliminary design

To complete this task all the necessary parameters already known: the geometrical dimensions of the landing area, the minimum thickness of the plate, the scantling. Because for the scantling of the landing are no related rules, optimum dimensions are used, as showed in fig.43.

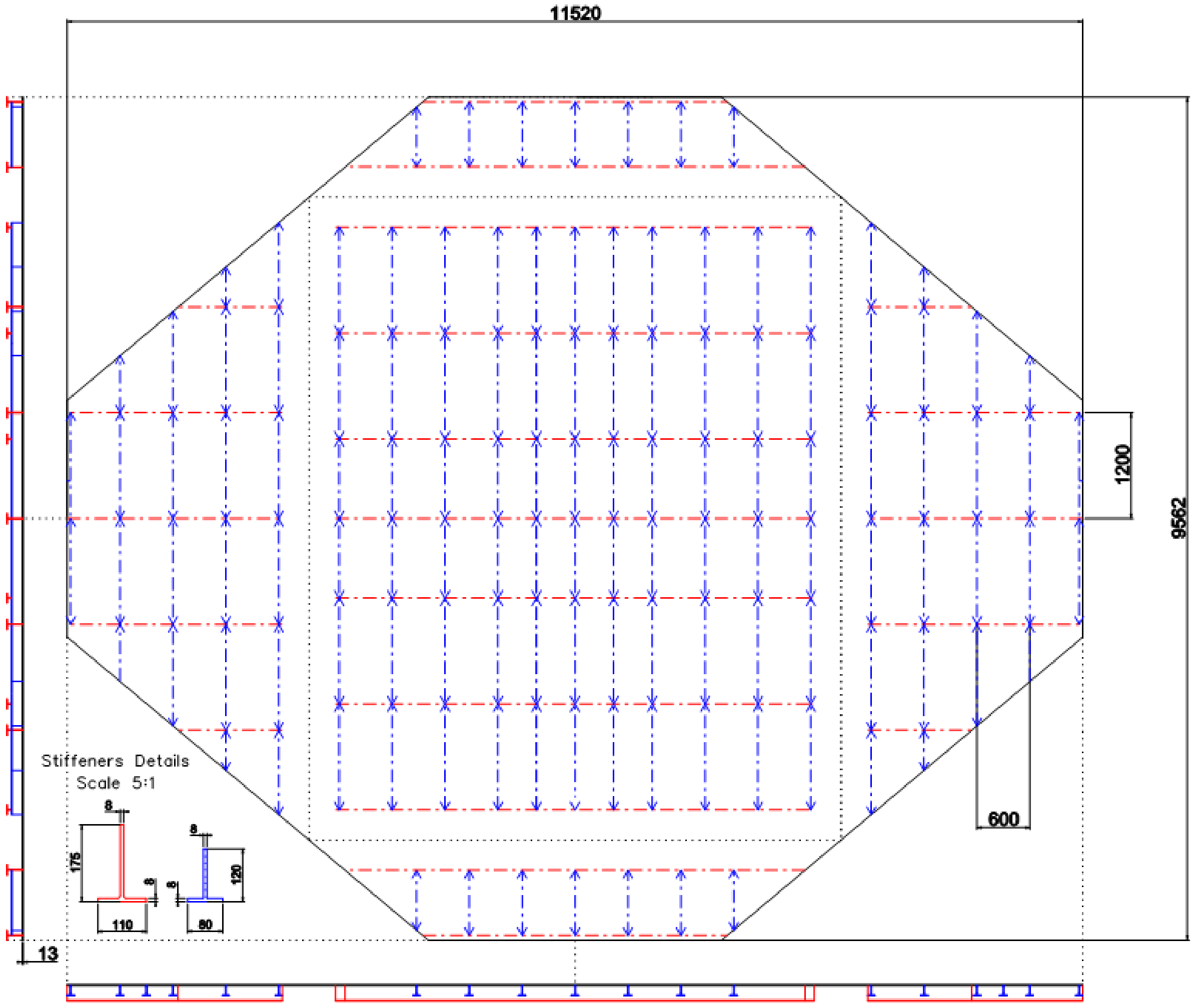

Figure 43.Structural scantling of the landing area

As it was mentioned before for a helicopter landing area it doesn’t exist structural scantling, hereby as it was show in the previous sub-section the stiffener spacing for the primary stiffeners is taken 1200 mm, and the secondary stiffeners as 600 mm, as represented in fig.43.It can be notice that in the middle of the landing area the spacing is reduced, due to the operational area of the helicopter, during requested landing.

4.2.4. Structural weight analysis

As it was mention in the minimum plate thickness sub-section, due to the significantly high value obtained for the minimum required plate thickness, even if as base material aluminum is used, a small structural weight shall be considered.

Hereby, through table 6.a small weight analysis is carried out:

Table 7.Weight analysis of the obtained landing area following the LR structural requirements.

L	B	t	NPS	NSS	Al_{Sheet}	T stiff	Plate	Stiffeners	Wt_heli_deck
mm	mm	mm	-	-	kg/mm^3	kg/mm	kg	kg	kg
11520	9562	13	8	21	0.0000027	0.00816	4993	2391	7384

Where,

L – Landing area length;

B – Landing area breath;

t – Plate thickness;

NPS – Number of primary stiffeners;

NSS – number of secondary stiffeners;

It can be notice that just the weight of the structure is significantly high, without considering the stiffeners, and the furthermore mechanism of the foldable helideck which is still has to be implemented. It could be reduced the structural scantling spacing, in order to obtained a smaller plate thickness, but this could influence dramatically the mechanism, having on each foldable parts more reinforcements. Therefore in order to reduce the structural weight, reduce the reinforcement, and cost, a sandwich structure is proposed for further analysis.

3.3. Preliminary structural assessment

3.3.1. Introduction

As it was been showed in the previous section using a simple stiffened plate, and applying the requirements of scantling offered by Lloyd’s Register rule book, it could simplify and offer a quick strength design stage, but unfortunately the weight of the landing area is a bit to height, even if aluminum is chosen as base material. This reason and others already related in the previous section, it’s “pushing” as like designers to other alternatives, like sandwich panels. Unfortunately is no practical example in using sandwich structures in landing area construction, hereby the strength design stage it’s a bit complicated, a new and simple workflow has to be developed in such a way to can be obtained a strength certification for the new landing area. The “stresses” induced by the helicopter during the worst emergency landing, or any operation on the surface of the landing area can’t exceed the ones given by the rules.

Now, about sandwich structures it’s a long history, unfortunately to adapt them to any particular application they should be analyzed very carefully.

Main principles

Through a simple introduction in sandwich panel theory it can be show the main principles and advantages in using sandwich structures. Generally sandwich structures are built up from three elements: two faces, a core and joints, see the figure below:

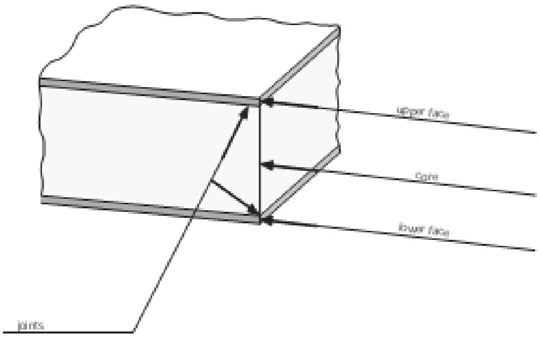

Figure 44 Sandwich structure

Every part has its specific function to make it work as a unit. The aim is to use the material with a maximum of efficiency. The two faces are placed at a distance from each other to increase the moment of inertia, and thereby the flexural rigidity, about the neutral axis of the structure. A comparison could be made with a solid beam. A Sandwich beam of the same width and weight as a solid beam has a remarkably higher stiffness because of its higher moment of inertia.

Every each of the components have special role in the strength or behavior of the overall structure during any loading condition.

<u>*The faces*</u>

The faces carry the tensile and compressive stresses in the sandwich. The local flexural rigidity is so small that it can often be ignored. Conventional materials such as steel, stainless steel and aluminum are often used for face material. In many cases it is also suitable to choose fiber- or glass- reinforced plastics as face materials. These materials are very easy to apply. Reinforced plastics can be tailored to fulfill a range of demands like anisotropic mechanical properties, freedom of design, excellent surface finish etc.

Faces also carry local pressure. When the local pressure is high the faces should be dimensioned for the shear forces connected to it.

<u>*The core*</u>

The core has several important functions. It has to be stiff enough to keep the distance between the faces constant. It must also be so rigid in shear that the faces do not slide over each other. The shear rigidity forces the faces to cooperate with each other. If the core is weak in shear the faces do not cooperate and the sandwich will lose its stiffness.

Choose of the structure

Now, the previous small sections proved the advantages and the characteristics in using sandwich panels, hereby the chosen sandwich structure is extrusion aluminum hollow profile, with inclined foam cores, see fig.45.

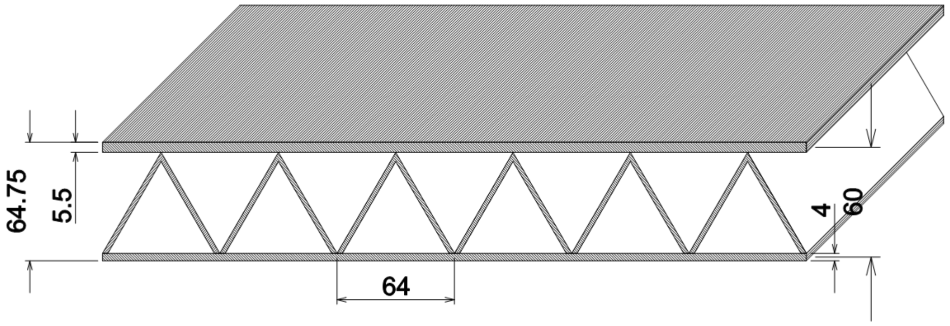

Figure 45. Aluminum extrusion profile with inclined cores

One of the most particular reasons of choosing aluminum extrusion profiles(Seung Il Seal, Keon Ho Sonl), beside his light weight, is his particular strength which is relatively equal in his longitudinal and transvers direction, this will reduce the necessary of using transvers frames to support longitudinal members it will be relatively unnecessary, this being proved also by numerical and FEM analysis. This results in omission of intersection between longitudinal members and transvers frames reduce also the fabrication cost, but also proves more advantages from weight and fabrication time point of view, than the design obtained for a simply build up structure(see previous Modeling section). The advantages can continue in less weld lines, and especially strengthening around joints by shape cause reduction of welding deformations. And also, as was already related from sandwich panel theory double skin plates with core void space, sound transmission loss increases compared with single skin plates. Noise reduction is one of the most important properties of hollow extrusion profile, this particular property already introduced in high speed vessel construction, but also in aircraft industry, where these properties are essential.

As it was mentioned aluminum hollow extrusion profiles have various useful particularities, so high speed rolling stocks developed recently adopt aluminum hollow extrusion profile as main structural member.

Going back to the problem, helicopters during emergency can induce high sound disturbance, knowing this aluminum extrusion profiles may solve this problem, knowing also that this structure will be implemented an a yacht where, aesthetic and reduced noise are particular important. Having also relatively similar strength in longitudinal and transvers direction, will lead to relatively similar result from strength point of view, which offers similar strength for the landing area in any direction, so whatever is the predefined direction of the requested landing, the pilot during emergency landing may land in any position, direction related to the landing area, the landing area will have relatively the same strength.

Structural characteristics

In order to design aluminum hollow extrusion profiles, characteristics of structural behavior of this profile should be clearly understood. As hollow extrusion profiles are 3 dimensional structures, 3 dimensional structural analyses are necessary. Being an extrusion, mainly his deformation it should be 3 dimensional, which means that all of the components of the profile under any particular loading should deform as one.

3.3.2. Theoretical structural assessment

Definition of the physical problem

As it was already defined, the aim of this section is to verify if the designed landing area structural strength can sustain the operations made by the helicopter upon the helideck surface. The deflection and stresses induced by the helicopter to the landing area will be analyzed using mathematical and analytical methods, in order to verify if the obtained results are correct.

Therefore, to fulfill this analysis the physical problem has to be very well defined. The loading condition has been defined in the previous section, making the assumption that the helicopter during his worst landing condition will touch the surface of the landing area upon one slink through an area of 300x64 mm. Now, for the landing area is considered the biggest distance limited by two longitudinal stiffeners, see fig.46. Therefore, the biggest distance limited by to stiffeners, defined in the previous sections, is 1904 mm, his length being 6077 mm.

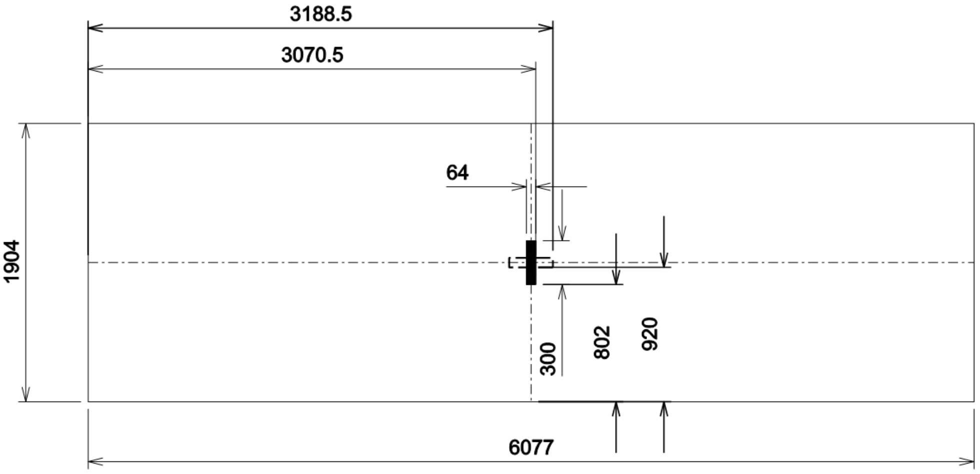

Figure 46.Top view of the biggest unstiffened pacing of the landing area, limited by two stiffeners

In fig.46 the black area represent the landing of the helicopter in transvers direction to the landing area, and the blank rectangular represents the longitudinal landing of the helicopter (required). The plate is considered simple supported in all of his 4 edges, the weight of the helicopter being distributed all around the contact slink area, 300x64 mm.

Notations

D_x – flexural rigidity of the plate in x direction;

D_y – flexural rigidity of the plate in y direction;

G_{xy} – torsional rigidity of the plate;

G –shear modulus of aluminum;

p – Uniform pressure;

p_l – uniformly distributed loading (F/L2);

w – Deflection;

M_x, M_y, M_{xy} – bending moments per unit length on planes normal to x and y directions and twisting moment per unit length;

V, Vy – equivalent shear forces per unit length acting on planes normal to x and y axes;

L_x, L_y – length of plate in x and y directions;

h – Depth of the extrusion profile;

E – Young modulus of aluminum;

ν – Poisson's ratio;

m, n – are odd integers;

g – Acceleration gravity;

x, y- coordinates of the rectangular loading patch on the plate.

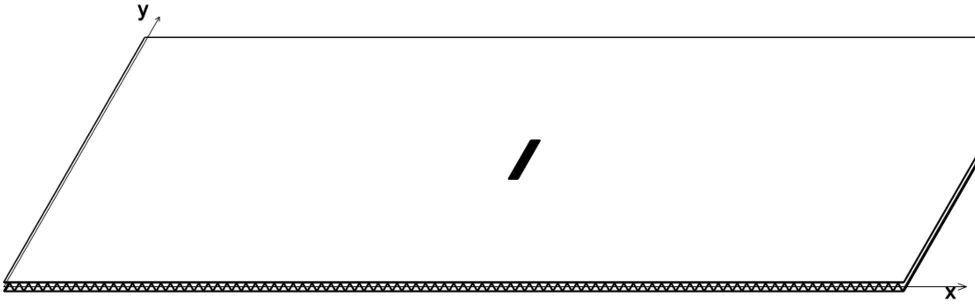

Figure 47.Landing skid touching area, in the middle of biggest distance limited by two stiffeners.

Fig.47 represents the biggest unstiffened area of the helideck, on which the patch in the middle of the plate represents the smallest are of one landing slink, thorough which is assumed that the helicopter will touch the surface of the helideck. Generally the same condition being assumed (see table 7), like in the section where the initial helideck strength was assessed, any other differences are mentioned during the analysis.

Table 8. Input data

L_X	L_Y	t_{up}	t_{lo}	α=a/b	t_c	h	S_p
[mm]	[mm]	[mm]	[mm]	-	[mm]	[mm]	[mm]
6077	1904	5.50	4.00	3.19	2.50	60.00	64.00

p1	H_{SL}	H_{SW}	H_F	E_{DL}	H_W
[N/mm^2]	[mm]	[mm]	[N]	-	[kg]
2.3	300	64	17658	2.5	1800

E	K_c	υ	g
[N/mm^2]	-	-	m/s^2
7.0E+04	4	0.334	9.81

Further, the aluminum extrusion profile structural strength will be analyzed, but to do this first some local characteristics of the profile will be evaluated (using the TALAT lecture notes, axial force resistance of orthotropic double-skin plate, by Torsten Höglund, 1999), which will highlight the strength of the extrusion aluminum profile. Fig.48 shows a detailed local section of the extrusion profile.

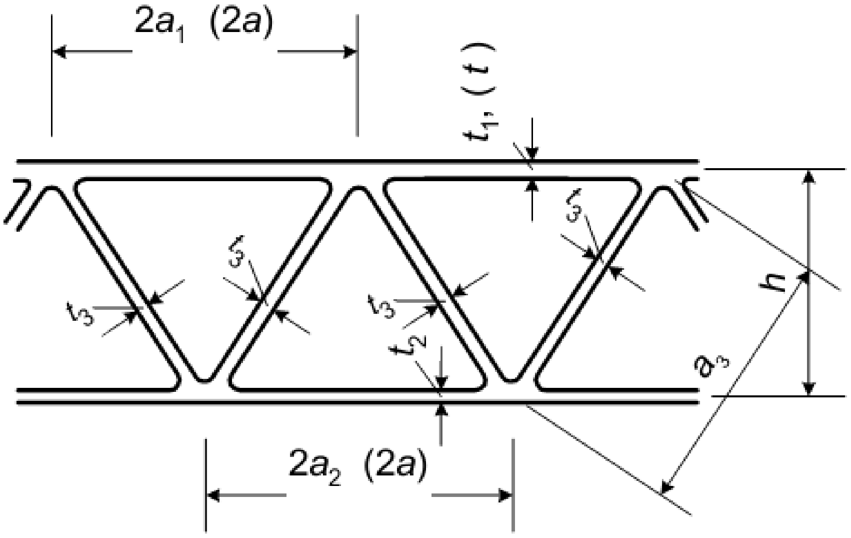

Figure 48.Aluminum extrusion profile section view

Half bottom flange: a_2=a; a_1=a; a=$\frac{1}{2}s_p$; a=32 mm;

Width of the web

$$a_3 = \sqrt{a_1{}^2 + h^2} = 68\,mm \tag{18}$$

Cross sectional area

$$A = 2t_{up} * a_1 + 2t_{lo} * a_2 + 2t_c * a_3 \tag{19}$$

$$A = 948\,mm^2$$

Gravity center

$$\mathrm{e} = \frac{2t_{lo} * \mathrm{a}_2 \ + \ 2t_c * \mathrm{a}_3 * \frac{h}{2}}{A} \tag{20}$$

$$e = 26.962\, mm$$

Second moment of area:

$$\mathrm{I}_L = \ 2t_{lo} * \mathrm{a}_2 * h^2 \ + \ 2t_c * \mathrm{a}_3 * \frac{h^2}{3} \ - (A * e^2) \tag{21}$$

$$\mathrm{I}_L = 6.405 * 10^5\ mm^4$$

Torsional Constant

$$\mathrm{I}_T = \frac{4\ h\ \ a_1 + a_2\ \ ^2}{\frac{2a_1}{t_1} + \frac{2a_2}{t_2} + \frac{2a_3}{t_3}} \tag{22}$$

$$\mathrm{I}_T = 7.190 * 10^5\ mm^4$$

Flexural rigidities may be expressed as:

$$D_x = \frac{Et_1h^2}{2} \tag{23}$$

$$D_x = 6.930 * 10^8\ N * mm$$

$$D_y = \frac{Et_1t_2h^2}{t_1 + t_2} \tag{24}$$

$$D_y = 5.836 * 10^8 N * mm$$

$$\mathrm{H} = \frac{G\mathrm{I}_T}{2a_1} \tag{25}$$

$$\mathrm{G} = \frac{E}{2(1 + \vartheta)} \tag{26}$$

$$\mathrm{G} = 2.624 * 10^4 \frac{N}{mm^2}$$

$$\mathrm{H} = 2.947 * 10^8\ N * mm$$

Furthermore the structural strength of the extrusion profile was calculated (Walter D. Pilkey, 2005). Therefore the deflection of a simple plate (i.e., isotropic, uniform plate) is governed by a linear partial differential as showed in Eq. 26.

$$\nabla^4 w = \frac{\partial^4 w}{\partial x^4} + 2\frac{\partial^4 w}{\partial x^2 \partial y^2} + \frac{\partial^4 w}{\partial y^4} = \frac{P}{D} - \frac{\rho}{D}\frac{\partial^2 w}{\partial t^2} \tag{27}$$

$$\nabla^4 = \frac{\partial^4 w}{\partial x^4} + 2\frac{\partial^4 w}{\partial x^2 \partial y^2} + \frac{\partial^4 w}{\partial y^4} = \ \ \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{x^2 \partial y^2}\ \ ^2 = \nabla^2 \nabla^2 \tag{28}$$

The used sign convention for a simple rectangular plate is represented in **FIG,** on which the application will be based.

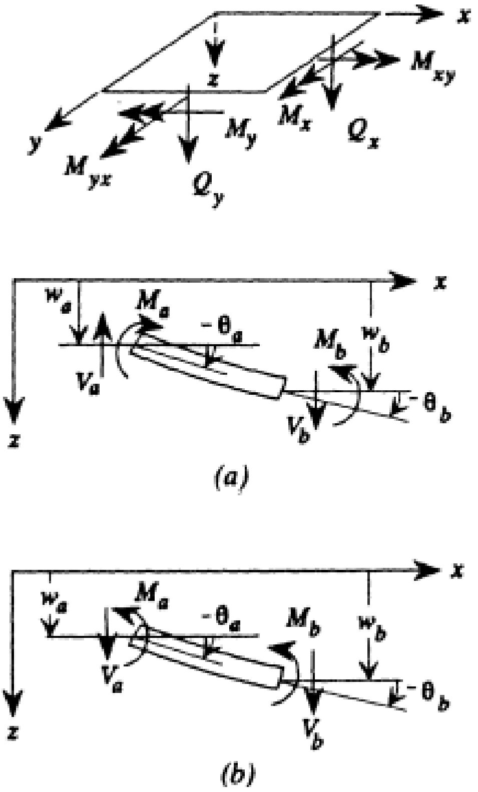

Figure 49.Sign conventions for rectangular plates: (a) sign convention 1 (transfer matrices); (b) sign convention 2 (stiffness matrices).

Governing differential equation for orthotropic plate under uniform pressure it can be written as it follows in Eq. 28.

$$D_x \frac{\partial^4 w}{\partial x^4} + 2H \frac{\partial^4 w}{\partial x^2 \partial y^2} + D_y \frac{\partial^4 w}{\partial y^4} = P \tag{29}$$

A response of a plate with all four edges simply supported is given by Eq. 29.The parameters for various loadings are also provided in the following equations. These formulas are obtained by expanding the deflection w and loading P in the form:

$$w = \mathop{}\limits_{n=1}^{\infty} \mathop{}\limits_{m=1}^{\infty} K_m \, sin \frac{n\pi x}{L_x} sin \frac{m\pi y}{L_y} \tag{30}$$

$$P = \mathop{}\limits_{n=1}^{\infty} \mathop{}\limits_{m=1}^{\infty} a_{mn} \, sin \frac{n\pi x}{L_x} sin \frac{m\pi y}{L_y} \tag{31}$$

Where K_m can by expressed through Eq. 31, as follows:

$$K_m = \frac{a_{mn}}{D\pi^4 \quad \frac{n^2}{{L_x}^2} + \frac{m^2}{{L_y}^2} \quad ^2} \quad where, \quad n, m = 1,3,5 \ldots \tag{32}$$

Where, D is given by the Eqs.22-23, the definition of a_{mn} is represented in **FIG,** and expressed as show in Eq. 32.

Figure 50. Uniform rectangular load

First parameter a_{mn} for a uniform rectangular distributed load (see figure above) can be written as:

$$a_{mn} = \frac{4p_1}{mn\pi^2} \quad cos\frac{n\pi a_1}{L_x} - cos\frac{m\pi a_2}{L_x} \quad cos\frac{n\pi b_1}{L_y} - cos\frac{m\pi b_2}{L_y} \tag{33}$$

Substituting Eq.32 into Eq. 31, K_m, and furthermore this in to the governing Eq. 29 to obtain the total deflection, w. The convergence, however, can be slow for concentrated and discontinuous loads, the solution for the governing Eq. 29 for a simply supported plate and central uniform rectangular load can be written as follows:

$$w = \frac{4p_1}{\pi^6} \underset{n=1}{\overset{\infty}{}} \underset{m=1}{\overset{\infty}{}} \frac{sin\frac{n\pi x}{L_x} sin\frac{m\pi y}{L_y} \quad cos\frac{n\pi a_1}{L_x} - cos\frac{m\pi a_2}{L_x} \quad cos\frac{n\pi b_1}{L_y} - cos\frac{m\pi b_2}{L_y}}{mn \quad D_x\frac{m^4}{{L_x}^4} + 2H\frac{m^2n^2}{{L_x}^2{L_y}^2} + D_y\frac{n^4w}{{L_y}^4}} \tag{34}$$

Table 9. Geometrical position of the helicopter landing slinks on the considered plate, as showed in **FIG.**

a1	a2	b1	b2	y	x	n	m
mm	mm	mm	mm	mm	mm	-	-
3006.5	3070.5	802	1102	952	3038.5	1	1

The maximum deflection will occur at the center of the plate where,$x = \frac{1}{2}L * \alpha; y = \frac{1}{2}L$, where $\alpha = \frac{L_x}{L_y} = 3.19$. From Eq. (16) it can be obtained:

$$w = \frac{4 * p_1}{\pi^6} \quad \frac{1 \ * \ 0.0331 \ * \ 0.49}{1 * 1 * \ 5.081 * 10^{-7} + 1.422 * 10^{-6} + 4.44 * 10^{-5}} \quad = \frac{4 * p_1}{\pi^6} * \ 349.8401$$

$$w = 3.3466\,mm$$

It can be noted that deflection series converges rapidly so that the summation of two terms provides sufficient accuracy for practical purposes.

Furthermore the bending moment can be obtained from the following differential equations:

$$M_x = - \quad D_x \frac{\partial^2 w}{\partial x^2} + \vartheta_y \frac{\partial^2 w}{\partial y^2} \tag{35}$$

$$M_y = - \quad D_y \frac{\partial^2 w}{\partial y^2} + \vartheta_x \frac{\partial^2 w}{\partial x^2} \tag{36}$$

$$M_{xy} = 2G_{xy} \quad \frac{\partial^2 w}{\partial x \partial y} \quad = -M_{xy} \tag{37}$$

From Eqs.34-35 the maximum bending moments are found in a similar fashion as the maximum deflection. They will occur at $x = \frac{1}{2} L * \alpha; y = \frac{1}{2} L$. Examination of the moment expression shows that they converge more slowly than the deflection series. At the center, four terms provide sufficient accuracy. More terms are required as the moments are computed closer to the edges of the loading patch (helicopter landing slink). Therefore the bending moment in the along x axis, can be expressed as follows:

$$M_x = D_x \pi^2 \sum_{n=1}^{\infty} \sum_{m=1}^{\infty} K_m \quad \frac{n}{L_x}^{2} + \vartheta \quad \frac{m}{L_y}^{2} \quad sin \frac{n\pi x}{L_x} sin \frac{m\pi y}{L_y} \tag{38}$$

$$M_x = D_x \pi^2 * 2.8411 * \quad 2.708 * 10^{-7} \quad + 0.334 * \quad 2.758 * 10^{-7} \quad * (1)$$

$$M_x = 2{,}197 * 10^3 \; N$$

In the same way it may be expressed the maximum bending moment in the y direction, where the moment should be higher due to the fact that the cores of the plate are not acting in the y direction.

$$M_y = D_x \pi^2 \sum_{n=1}^{\infty} \sum_{m=1}^{\infty} K_m \quad \frac{n}{L_y}^{2} + \vartheta \quad \frac{m}{L_x}^{2} \quad sin \frac{n\pi x}{L_x} sin \frac{m\pi y}{L_y} \tag{39}$$

$$M_y = 5{,}160 * 10^3 \; N$$

Therefore bending stresses due to bending moments can be calculated by the following formulas:

$$\sigma_x = \frac{E M_x h}{D_x} \tag{40}$$

After substitution of each term:

$$\sigma_x = \frac{7 * 10^4 * 2{,}197 * 10^3 * 60}{6{,}930 * 10^8}$$

$$\sigma_x = 13{,}3123\ \frac{N}{mm^2}$$

The equation for the bending stress in the y direction:

$$\sigma_y = \frac{EM_yh}{D_y} \tag{41}$$

$$\sigma_y = \frac{7 * 10^4 * 5.160 * 10^3 * 60}{5.836 * 10^8}$$

$$\sigma_y = 37{,}1329\ \frac{N}{mm^2}$$

It can be notice as predicted that the maximum bending stress is on y direction, the hollow extrusion cores of the plate are offering more rigidity in the x direction, hereby also the bending stress is smaller more or less 3 times then an the y direction.

Now, the shear forces can be also expressed by the following equations:

$$V_x = -\frac{\partial}{\partial x}\left(D_x\frac{\partial^2 w}{\partial x^2} + H\frac{\partial^2 w}{\partial y^2}\right) - \frac{\partial M_{xy}}{\partial y} \tag{42}$$

$$V_y = -\frac{\partial}{\partial y}\left(D_y\frac{\partial^2 w}{\partial y^2} + H\frac{\partial^2 w}{\partial x^2}\right) - \frac{\partial M_{xy}}{\partial x} \tag{43}$$

Global structural behaviors of aluminum hollow extrusion profile show the particularity of orthotropic plates. Shear stresses at the edges are affected by the depth of the profile, h, because of the distribution of the rotational angles, which is much varied at the edges of the landing slink, and this non-uniformity causes twisting at the edges. Therefore the deep and large twisting of the double walled core results large shear stresses at the edges, close to the center of the cores. Hereby the shear forces are V_x and V_y determined from responses of the above Eqs.41-42. The reactions at the edge can be found from the resulting expressions. For example, the reaction force along the x = 0 edge can be expressed from the differential equations as follows:

$$V_x = \pi^3 D_x a_3 \sum_{n=1}^{\infty}\sum_{m=1}^{\infty} K_{mn}\left[\left(\frac{n}{L_x}\right)^3 + (2-\vartheta)\frac{n}{L_x}\left(\frac{m}{L_y}\right)^2\right] cos\frac{n\pi x}{L_x}\, sin\frac{m\pi y}{L_y} \tag{44}$$

Substituting the already known terms, the shear force reaction along x=0 will become:

$$V_x = \pi^3 * (6{,}930 * 10^8) * 68 * 2{,}6939 * (8{,}008 * 10^{-11}) * 1$$

$$V_x = 315{,}206\ N$$

The reaction along y=0 edge will be calculated in the same fashion and expressed through the following equation:

$$V_y = \pi^3 D_y a_3 \overset{\infty}{\underset{n=1}{\ }} \overset{\infty}{\underset{m=1}{\ }} K_{mn} \ \frac{m}{L_y}^{\ 3} + \ 2 - \vartheta \ \frac{m}{L_y}\ \frac{n}{L_x}^{\ 2} \ sin\frac{n\pi x}{L_x} cos\frac{m\pi y}{L_y} \tag{45}$$

Now, knowing that the cores will not act along y axis, is expected that the reaction of the shear force along the y axis to be higher than along x. Knowing all the terms which are needed the express the shear reaction along y axis, it can be obtained:

$$V_y = \pi^3 * (5{,}836 * 10^8) * 68 * 3{,}144 * \ \ 1{,}685 * 10^{-10} \ \ * 1$$

$$V_y = 652{,}187\ N$$

Once knowing the shear force reaction along x, y directions, the shear stress can be expressed. As it was explained in the introduction part of this section, the maximum shear stress will occur close to the neutral axis, at the quarter edges of the loading patch, this means that the maximum shear stress shell be analyzed inside the cores of the plate, **FIG** proves this argument.

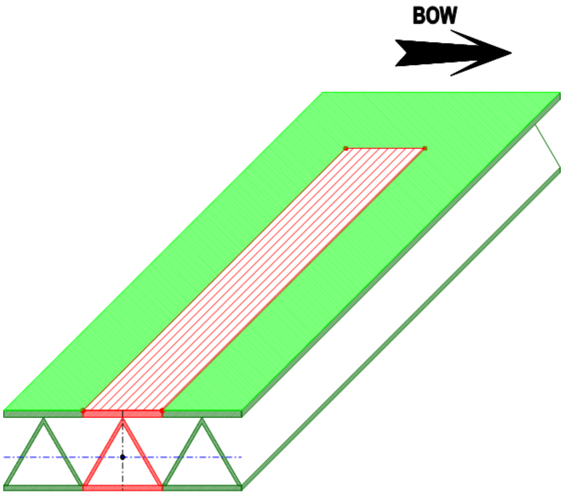

Figure 51. Section of the landing area around the landing slink load patch

FIG represents a sectional view of the landing area (green hatched area) around the loading patch (red hatched area) of one slink of the helicopter. The vertical blue axis represents the centroid of the structure, along which according to the theory is expected to be reach the maximum shear stress, due torsion, and twisting moment.

Therefore shear stress around the vertical axis x, can also be expressed by referring to the beam theory as follows:

$$\tau_x = \frac{V_x * W}{I * t_c} \tag{46}$$

Where,

W= Section modulus;

I= Second moment of area.

The sectional modulus, W, can be expressed as follows:

$$W = t_c * \ \frac{a}{2} - \frac{t_c}{2} \ * \ h + \ \frac{t_u}{2} \ + \ \frac{t_l}{2} \ - e \tag{47}$$

All the terms been already calculated the section modulus will become:

$$W = 2{,}5 * \ \frac{32}{2} - \frac{2{,}5}{2} \ * \ 60 + \ \frac{5{,}5}{2} \ + \ \frac{4}{2} \ - 26{,}962$$

$$W = 1393{,}432 \, mm^3$$

The next term is the second moment of area, which for a given core section will be:

$$I = \frac{{a_3}^3 * t_c}{12} \tag{48}$$

Substituting the terms:

$$I = \frac{68^3 * 2{,}5}{12}$$

$$I = 65506{,}67 \, mm^4$$

All terms being known, the maximum shear stress according to eq.46, inside the core, around the neutral axis will become:

$$\tau_x = \frac{315{,}206 * 1393{,}432}{65506{,}67 * 2{,}5}$$

$$\tau_x = 2{,}682 \, \frac{N}{mm^2}$$

Around the y axis, the maximum shear stress is defined in the same fashion, and expressed as follows:

$$\tau_y = \frac{V_y * W}{I * t_c} \tag{49}$$

Substituting the terms, the maximum shears will become:

$$\tau_y = 5{,}549 \, \frac{N}{mm^2}$$

Further the Von Mises stress can be expressed by the next equation:

$$\sigma_e = \ {\sigma_x}^2 + {\sigma_y}^2 - \sigma_x \sigma_y + 3\tau^2 \ ^{\frac{1}{2}} \tag{50}$$

All the terms being already known, the expression of eq.50 will become:

$$\sigma_e = \ (13{,}3123)^2 + 37{,}1329^2 - \ 13{,}3123 * 37{,}1329 \ + \ 3 * 5{,}549^2 \ ^{\frac{1}{2}}$$

$$\sigma_e = 33{,}972 \, \frac{N}{mm^2}$$

The structural analysis made represent the operation made by the helicopter during inappropriate landing, the slinks being parallel to the cores of the extrusion panel. In case of normal landing (requested), will land perpendicular to the landing area; locally this means that the cores will become perpendicular to the landing slinks see fig.52.

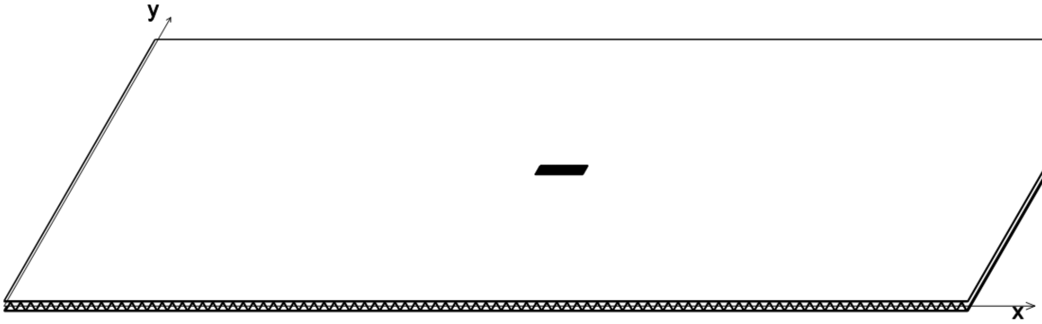

Figure 52. Landing slink position during requested landing

Table 10.The results obtained during the emergency landing case, using the same workflow developed:

Case 1	M_x	σ_x	M_y	σ_y	σ_N	σ_e	V_x	V_y	τ_{max}	w_{max}
	[N]	[N/mm^2]	[N]	[N/mm^2]	[N/mm^2]	[N/mm^2]	[N]	[N]	[N/mm^2]	mm
	2196.522	13.3122	5159.514	37.133	37.133	33.972	315.206	652.187	5.549	3.144
Case 2	M_x	σ_x	M_y	σ_y	σ_N	σ_e	V_x	V_y	τ_{max}	w_{max}
	[N]	[N/mm^2]	[N]	[N/mm^2]	[N/mm^2]	[N/mm^2]	[N]	[N]	[N/mm^2]	mm
	2215.956	13.430	5205.164	37.461	37.461	34.273	317.995	657.957	5.598	3.172

Case 1 represents the structural calculation made, and second Case represents the one showed in fig.53.

It can be noticed that the difference between the two landing cases is insignificantly small, which mean that choosing the aluminum extrusion profile was a good chose, the structure giving relatively equal strength, as was predicted, in his longitudinal and transvers direction.

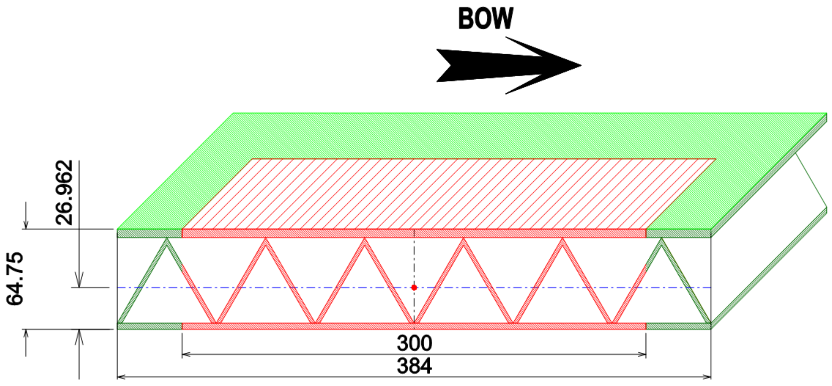

Figure 53. Section of the landing area around the landing slink load patch; Requested landing

Knowing all the stresses induced by the helicopter, the limit states for this stresses should be define. For this Lloyds Registers limit states formulations are used, which can be formulated as follows:

$$\sigma_{\max\_n\_p} = 0{,}75 * \sigma_y \tag{51}$$

Where,

$\sigma_{max\_n\_p}$ – maximum stress within the plate during normal landing;

σ_y – aluminum yielding strength, taken as σ_y=180 N/mm^2.

Therefore, the maximum stress within the plate during normal landing can go up to:

$$\sigma_{\max\_n\_p} = 117 \frac{N}{mm^2}$$

The stress within the plate during emergency landing of the helicopter can be expressed as follows:

$$\sigma_{\max\_e\_p} = 0{,}65 * \sigma_y \tag{52}$$

$$\sigma_{max\_e\_p} = 135 \frac{N}{mm^2}$$

It can be notice that the calculated stresses during the theoretical calculations are way below the maximum limit states requested by rules.

These were showed the next step therefore is to see if the obtained results through the developed theoretical workflow coincide with the finite element method.

3.3.3. Finite element method

Definition of the physical problem

As it was already discussed in the previous section, the same physical characteristics are applied to build up the virtual model in order to execute the analysis. It has been showed in the theoretical assessment that through the analysis carried out; it’s difficult to predict the working “mechanism”, behavior of the extrusion profile.

The presented finite element method it will be checked the behavior of the structure for the same cases analyzed in the theoretical structural assessment. Also other different cases were analyzed in order to predict the best solution possible to construct the final model. In the research will be not be showed, but the analysis carried out presented a better solution in using short cores in length, therefore this simplified also the final structural assessment.

Note that for the preliminary design stage it's enough to take the biggest unstiffened plate space

All the analyzed models were constructed in Siemens Nx, and further imported in the mentioned FE software, ANSYS solver.

Analysis

The both analyzed cases will be presented in parallel, in a way to be able to interpret and understand in best possible way the obtained results.

Fig.53 represents the case when loading patch is transversally distributed to the cores of the extrusion profile, respectively fig.54 the loading patch being parallel to the cores direction.

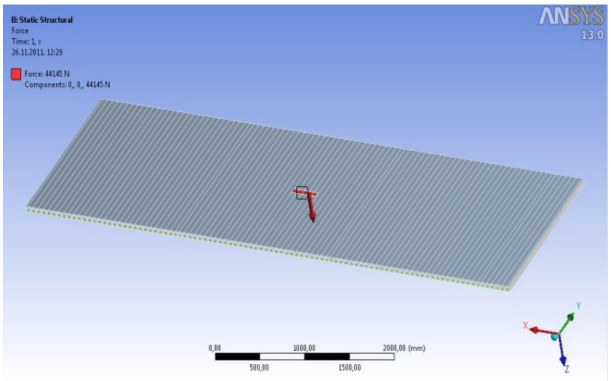

Figure 54.Transverse loading patch

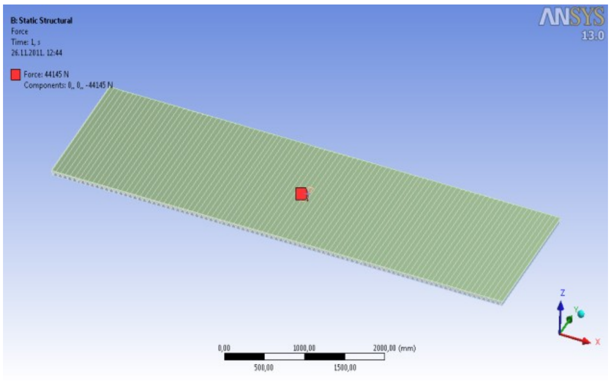

Figure 55. Longitudinal loading patch

An automatic fine mesh was used, the results showing significantly small structural errors in both cases, approximately a maximum value of 0,2; which was obtained in the cores of the aluminum extrusion, which means that mainly the shear stresses distribution was a bit influenced, but having a really small shear stress(see fig.) in the cores, this errors can be neglected.

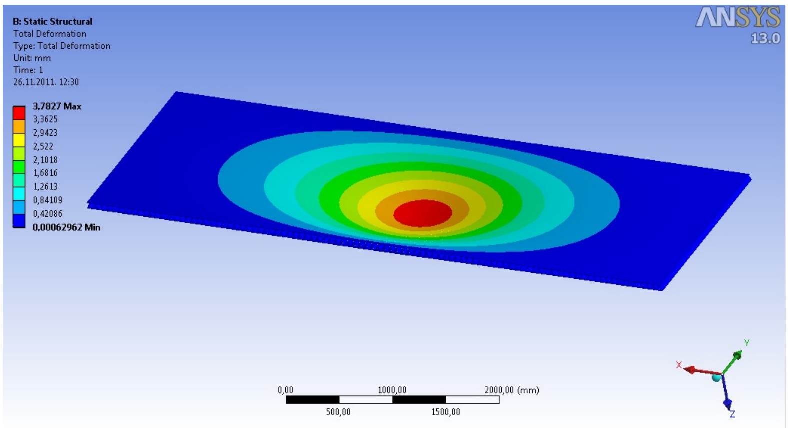

Figure 56.Extrusion profile deflection for transvers loading patch

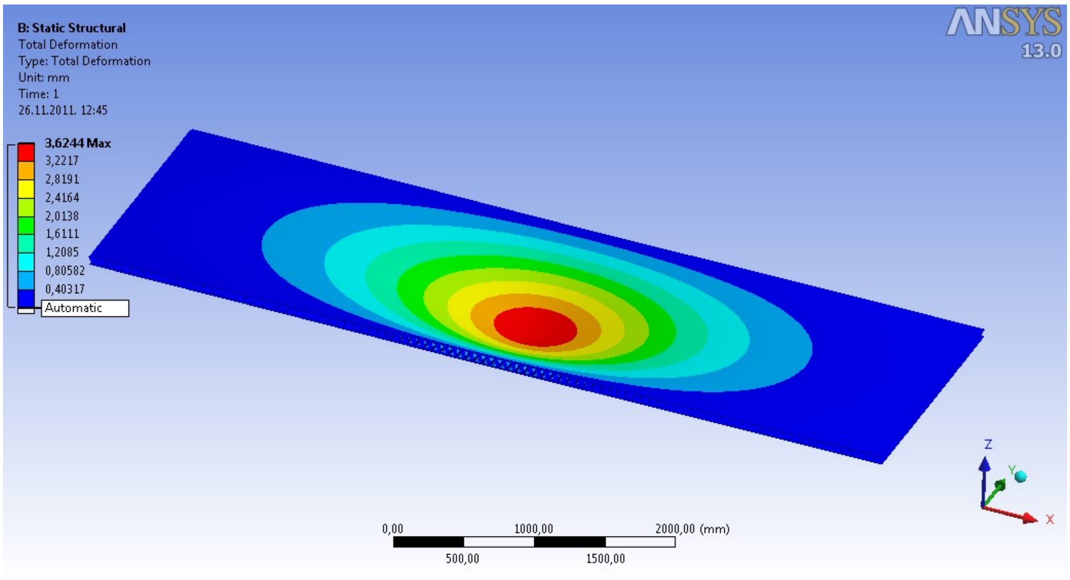

Figure 57. Extrusion profile deflection for longitudinal loading patch

The deflections obtained in both cases, are relatively small, 3.62-3.78 mm, see fig.54-55, and the maximum deflection due to bending is reached in the middle of the loading patch. The results being similar to the ones obtained in the theoretical calculation.

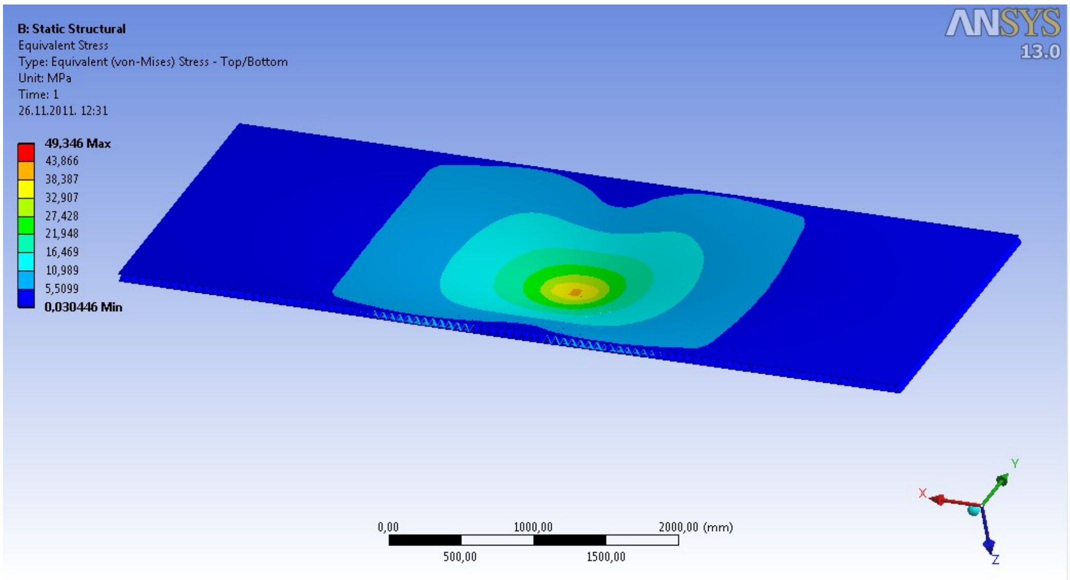

Figure 58.Von-Mises stress distribution for transvers loading

Furthermore, in fig.57-58 the Von-Mises stress distributions are represented, the maximum Von-misses stress in the transvers loading patch is reaching 49 MPa, and the longitudinal loading, 43 MPa. Von-Mises stress distribution is showing in this case also, relatively good agreement with the theoretical calculations.

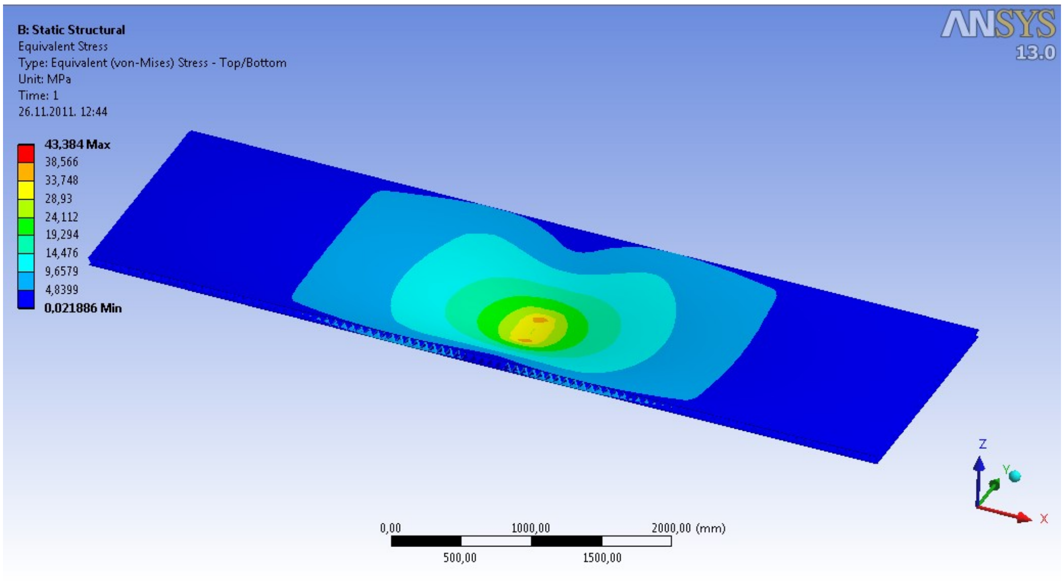

Figure 59. Von-Mises stress distribution for longitudinal loading patch

In the normal stress distribution, see fig.59-60, the maximum stress is reached in the upper plate, in the middle of the landing patch, again in the plate showing a bit higher flexural direction case when the loading path is oriented in the direction of the cores.

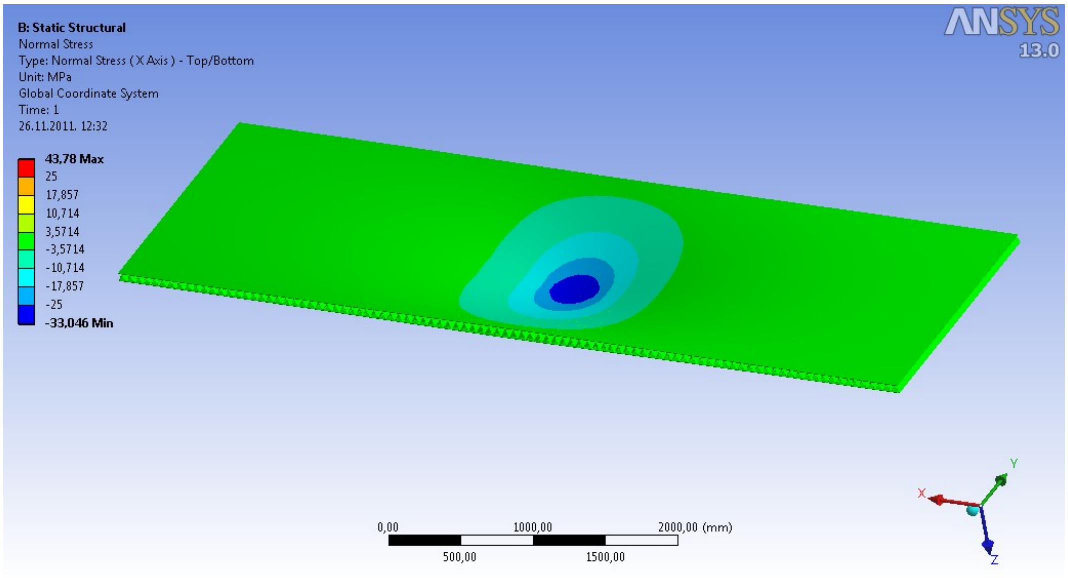

Figure 60.Normal stress distribution for transvers loading patch

The maximum normal stress in the transvers loading patch is reaching 43 MPa, in the second case 41 MPa, both cases are showing good agreement with the theoretical assessment.

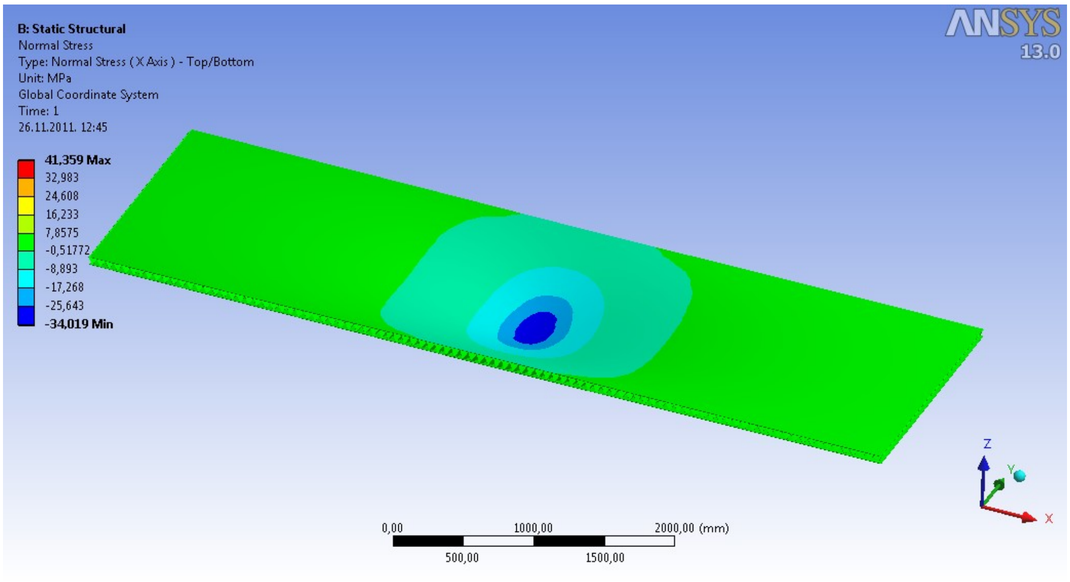

Figure 61. Normal stress distribution for transvers loading patch

The maximum shear stress is reached at the edges of the loading patch, in the transvers loading case, see fig.60, the shear stress reaching its maximum value close to the structure centroid, in the middle of the extrusion cores, 6.33 MPa.

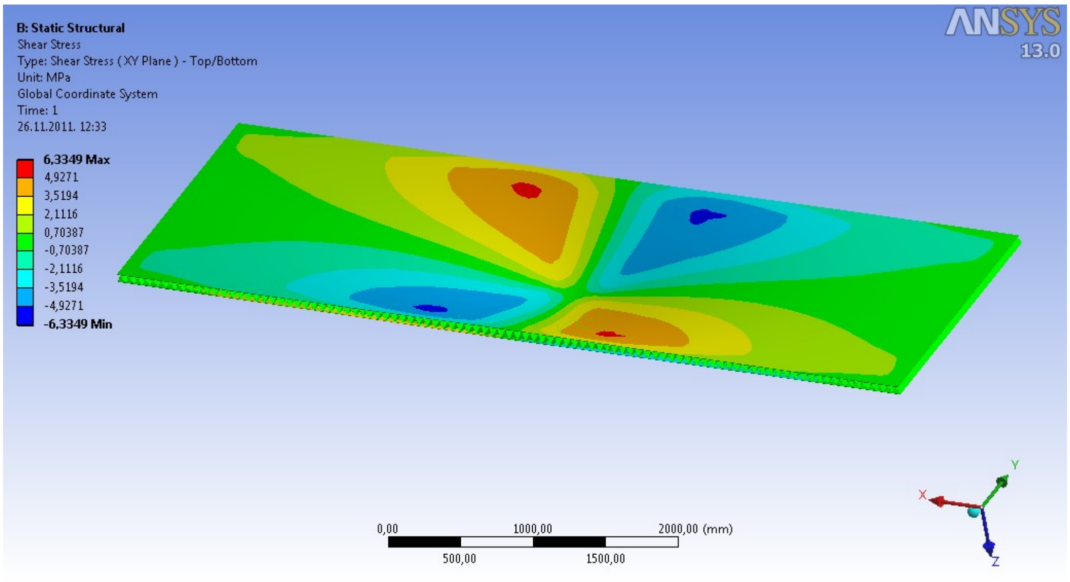

Figure 62.Shear stress distribution

In the longitudinal loading case the maximum shear stress its reaching his maximum in 6.32 MPa, really identically like in the first case and in the theoretical calculations. The small value of shear its also due to the cores, which as it was mentioned are playing an important role in the shear stress distribution, having inclined cores, the shear flow is passing smoothly through the structure, and the symmetrical cores are share-ring the stresses induced above them.

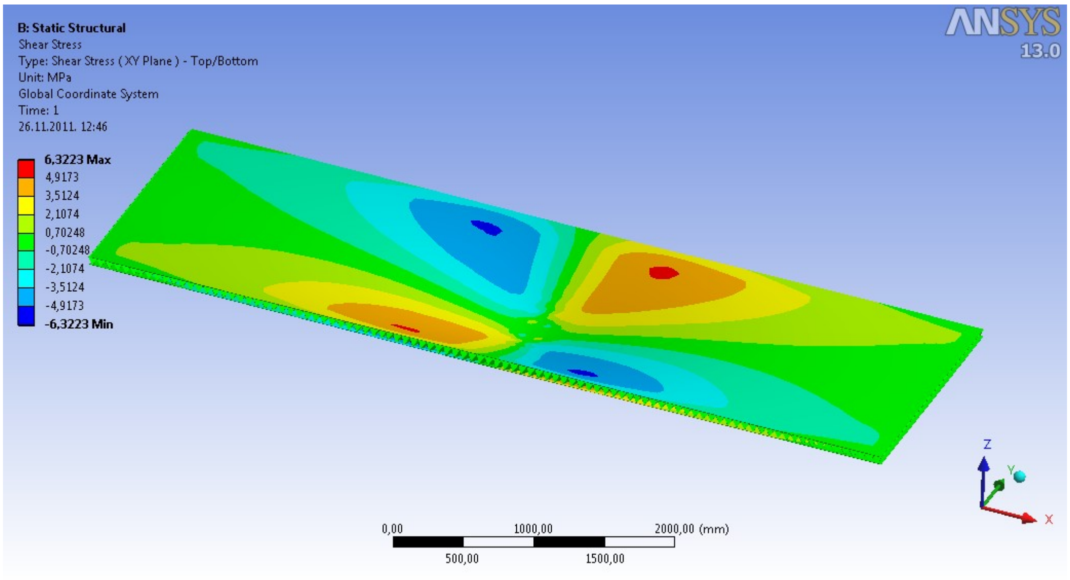

Figure 63.Shear stress distribution

It has been showed that the theoretical and analytical (FEM) approaches are showing a good agreement, and also aluminum extrusion profiles strength is recommending them in landing area design.

It can be also noted that all the analyzed physical properties of the aluminum extrusion profile are way below the limit strength required by the rules (see tables 11-12)

Table 11. Theoretical results

Case 1	w_max	σ_n_max	σ_e	τ_max
	mm	[N/mm^2]	[N/mm^2]	[N/mm^2]
	3.17	37.46	34.27	5.59
Case 2	w_max	σ_n_max	σ_e	τ_max
	mm	[N/mm^2]	[N/mm^2]	[N/mm^2]
	3.14	37.13	33.97	5.54

Table 12. Analytical results

Case 1	w_max	σ_n_max	σ_e	τ_max
	mm	[N/mm^2]	[N/mm^2]	[N/mm^2]
	3.782	43.78	49.3460	6.3349
Case 2	w_max	σ_n_max	σ_e	τ_max
	mm	[N/mm^2]	[N/mm^2]	[N/mm^2]
	3.624	41.35	43.3840	6.3223

3.4. Preliminary preview

This section serves as a conclusion, related to the fulfillment reached until this stage of the research. In order to check if the job done until this stage was correctly fulfilled, some loop check steps were developed.

Review of the preliminary modeling

To be able to achieve the best solution possible, the steps made until this stage were repeated more than once. Starting from the related chapter 3, and using the requirements developed and requested by the rules (which were developed in the first 2 chapters), the landing area was checked of all the requirements for certification were fulfilled until this stage.

Helideck Certification Agency (HCA)

As it was already presented in the early stage of the research, HCA represents the safety "structure" of the task; in order to achieve a fully certified helideck; HCA has to be involved directly in all of the stages. Hereby, a preliminary result of the new landing area was send to the Helideck Certification Agency, which is showed in detailed drawing and highlighted in Annex 3.

Unfortunately until now, no answer was given by HCA, so the assignment has to continue further based on the thrust that the research done until this stage is correctly fulfilled.

4. FINAL MODELING OF THE LANDING AREA

4.1. Design of the landing area

4.1.1. Structural modeling of the landing area

The geometrical and local structural strength were assigned in the previous chapters, therefor from now on it should be discussed about the landing area modeling. A small review can be done in order to show separate and the already accomplished task from the further needed ones. Therefore in fig.64 it can be notice the initial states of the research, with the helicopter landing area un the aft sundeck.

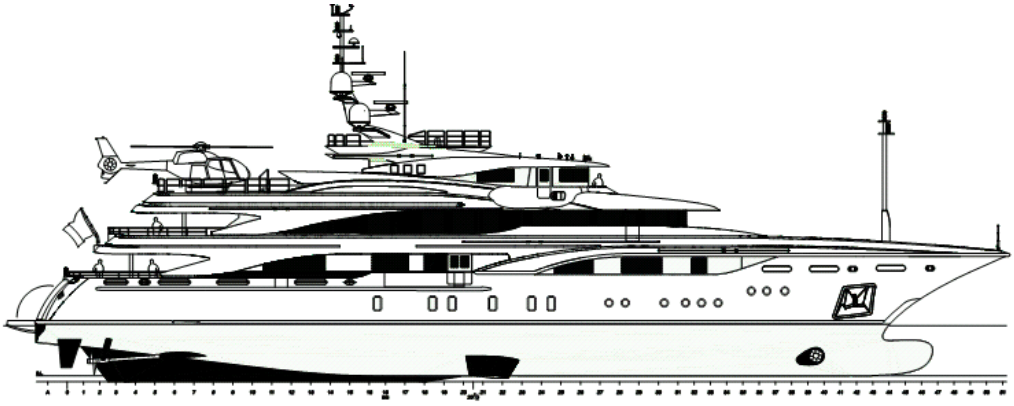

Figure 64. Initial landing area on the sundeck

Furthermore, a new helideck was designed, based on the geometrical requirements of CAA. Structural optimization was performed afterword's in order to fit the new foldable helideck within the aft sundecks structure, as showed in fig.65.

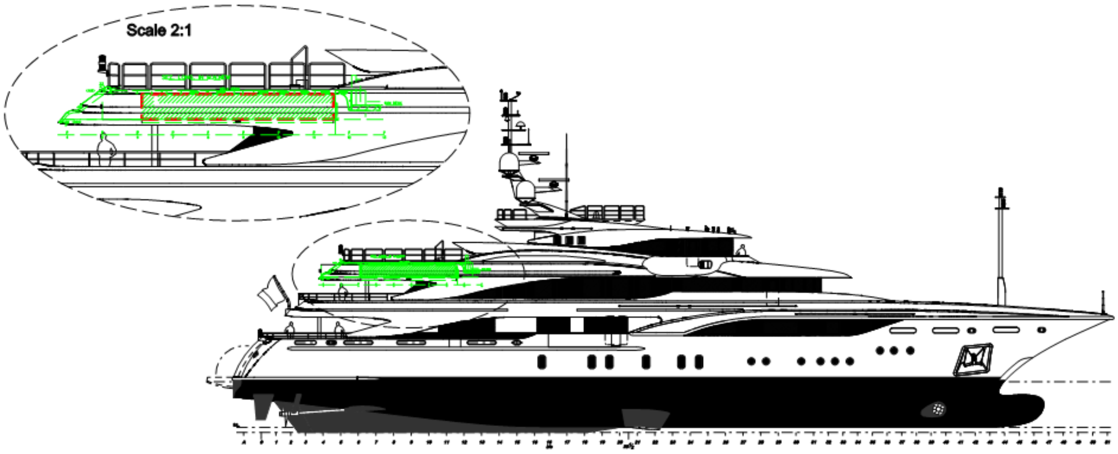

Figure 65. Proposal for the foldable helideck "housing"

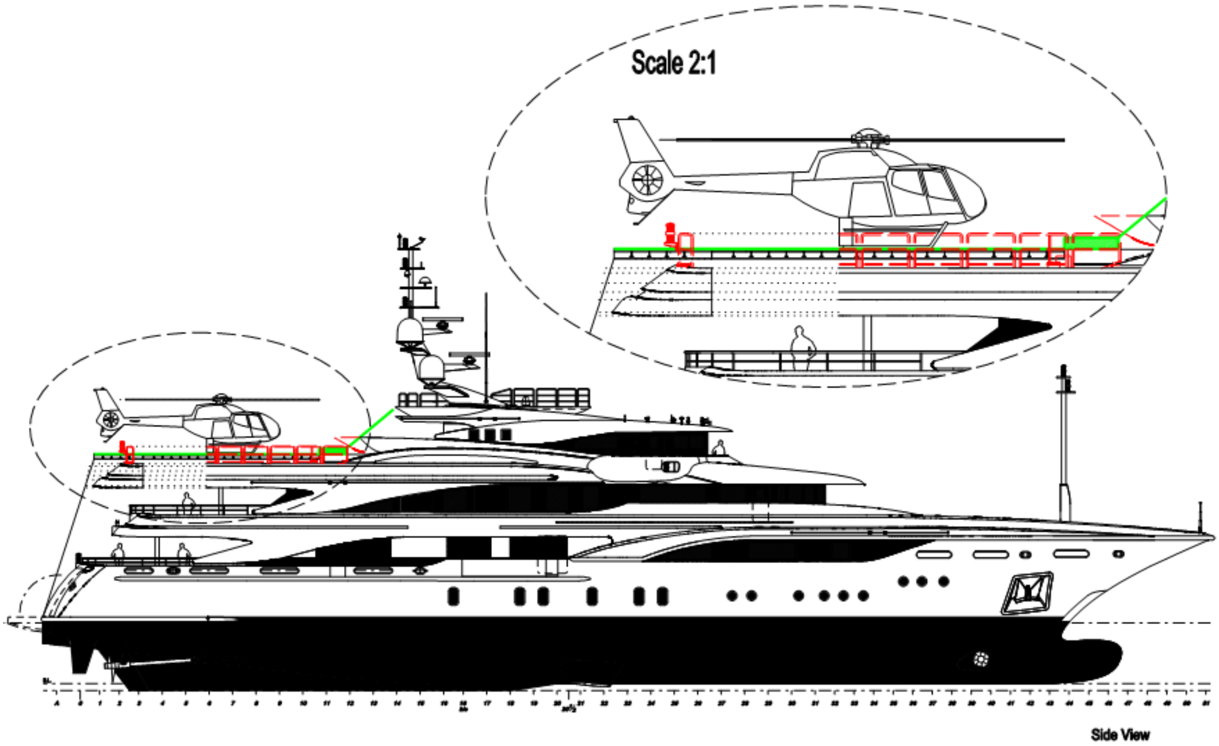

Figure 66. Folded helideck

Now, the new structure being “housed” within the sundeck structure, in order to fold it out, the aft part of the sundeck was proposed to be movable, as showed in fig.66. Therefore movable aft part of the sundeck it will make a translation, on two steerage arms in order to permit the folded helideck to come out. The handrails (see in fig.66, highlighted within red color) will be foldable ones, when landing operation is requested. The helideck final position, highlighted in fig.66 with green color, it’s also defined by CAA (Civil Aviation Authority) rules, as was presented in the geometrical constraints section, the hatched green square representing the obstruction free sector. The exact location of the helideck was also chosen in this manner to place its center of gravity more or less under the two stainless steel pillars, which are sustaining the aft sundeck from below. This reason “pushed” a bit the helideck in a small obstruction sector, the landing area interfering with the side shell (sharp red notation) of the superstructure, as showed within fig.66. Therefore the side shell was a bit modified in order to fulfill the CAA, OFS requirement.

Furthermore the structural scantling was based mainly on the foldable parts of the helideck. Being a sandwich structure it were considered just primary stiffeners, equal spaced on 1904 mm (see fig.67), as it was already proposed in the preliminary structural assessment modeling section.

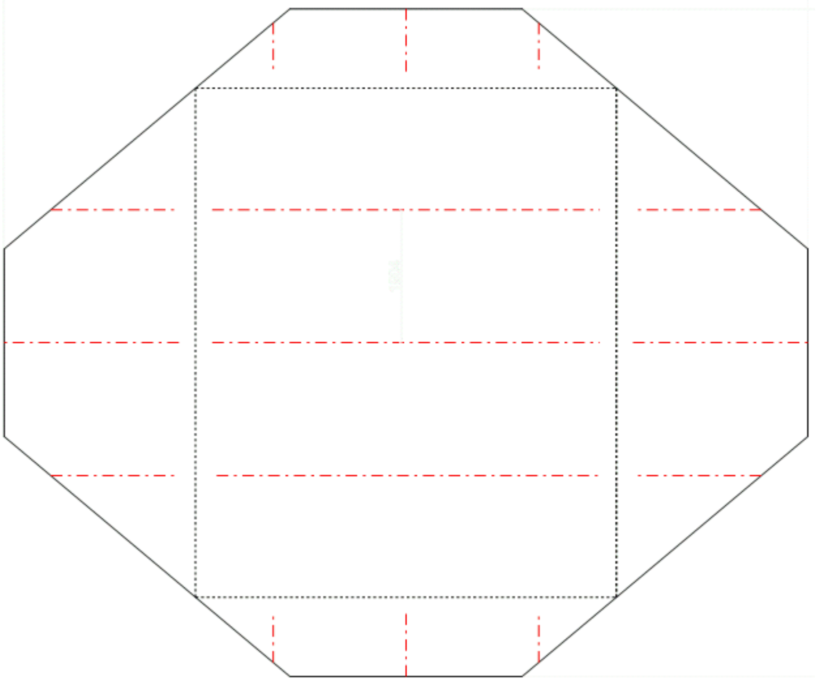

Figure 67. Structural scantling of the helideck

Now, knowing already the size of further folding sides plates of the helideck, it was proposed to well two solid aluminum profiles, one on the fix part the other on the foldable one, in order to reduce any damage of the helideck, during folding-unfolding, or even during helicopter operations upon the structure. Fig.68 represents this concept, the solid extrusion profiles being extruded on all length of the folding parts and fixed one, they being welded to the upper and lower plate of the sandwich panels.

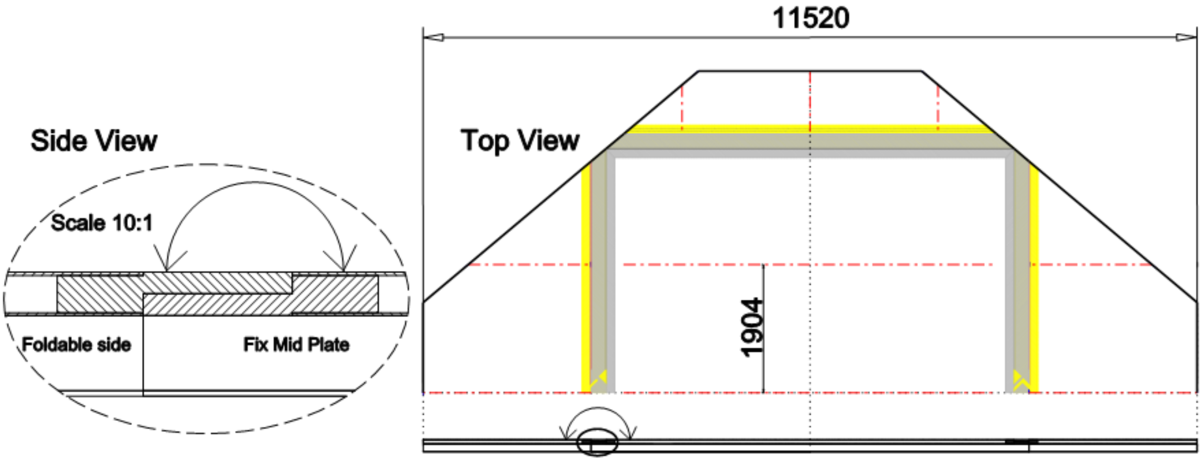

Figure 68. Folding area locally reinforcement

4.1.2. Design of the mechanism

Now, before performing any further design a small weight prediction shall be performed in order to estimate the helidecks each component weight. This weight assessment will help to predict the geometric size and necessary power of the pistons which will impose the motion of the foldable parts.

4.1.2.1. Weight analysis

Table 13. Helideck each component weight

M_p	L_{sp}	T_{sp}	M_{lc}	M_{tc}	S_m	S_{ls}	S_{ts}
kg	kg	kg	kg	kg	kg	kg	kg
1961	532	182	190	159	126	31	46

Where,

M_p – middle plate;

L_{sp} – longitudinal side plate;

T_{sp} – transvers side plate;

M_{lc} – middle longitudinal connections (solid aluminum extrusions);

M_{tc} – middle transvers connections;

S_m – middle plate stiffeners;

S_{ls} – longitudinal side plate stiffeners;

S_{ts} – transvers side plate stiffeners;

Table 14. Total weight helideck each components

Plate	Connections	Stiffeners	Wt_heli_deck	Wt_heli_deck
kg	kg	kg	kg	N
3390	699	408	4496	44090

Table 15. Assembled foldable parts total weight

Walsp	Walsp	Watsp	Watsp
kg	N	kg	N
754	7389	387	3800

Where,

Walsp – weight of assembled longitudinal side plate;

Watsp – weight of assembled transvers side plate;

4.1.2.2. Choose of the pistons

The chosen pistons were hydraulic ones, due to the small available place, but also because are giving much higher efficiency than pneumatic cylinders. Now, in order to predict the size and necessary power needed, some small calculation were performed. I the below table 16 is showed the required geometrical dimension, and power for the above calculated biggest foldable part, per one piston; note that one plate will be folded by two pistons.

Table 16. Hydraulic piston power and size prediction

b_cyl	d_Rod	Wlp	Ftp	Fp	p	p
[m]	[m]	Kg	N	N	bar	psi
0.07	0.035	754	7392	3696	13	188

p	Fpi	Q	Sp	Sr	T
N/mm^2	N	mm^3/s	mm/sec	mm/sec	kW
1.297E+06	3742	5.0E-04	130	173	0.65

A	a	Fr	t	FRA
m^2	m^2	N	s	m^3/sec
3.848E-03	9.621E-04	4990	60.00	0.03

Where,

b_cyl – bore of the piston cylinder;

d_Rod – diameter of the road;

Wlp – weight of the longitudinal foldable plate;

Ftp – total force of the foldable plate;

Fp – half force of the foldable plate;

P – Necessary pressure for one piston;

p – Pressure inside the piston, obtained from the difference between the areas, of the cylinder bore’s interior diameter and the rod;

Fpi – is the output force of one piston, for the given geometrical dimensions of the piston;

Q – Cylinder flow rate;

Sp – cylinder push speed;

Sr – cylinder retreat speed;

T – Torque of the cylinder;

A – Cylinder interior area;

a – road area;

Fr – required force, plate force multiplied with a safety coefficient.

It has been showed that in order to push the total weight of the plate, is needed two pistons, of 0,07 m diameter, every each of them has to be supplied with 13 bar.

Due to the fact that the plate will make a rotation during his folding, the pistons will have to react for all the angles of the rotation. In other words due to different angle of attack it will be pressure losses, but on the other hand also advantages. The next eq.53-54 were applied in order to predict the required power to a fully 180^0 rotation (see fig 70) made by one piston.

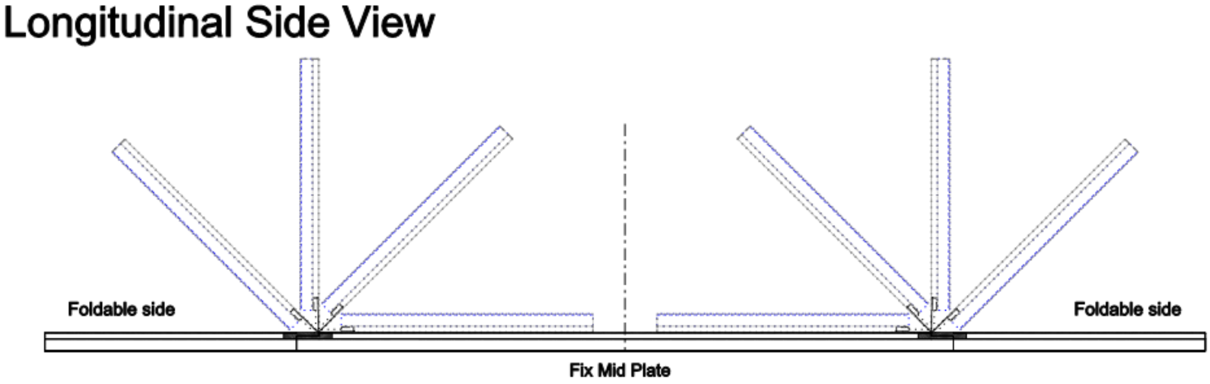

Figure 69. Longitudinal side plates during folding

Therefore, the required push and pull power was predicting in this way:

Required push power (foldable plate lifts, helideck closing):

$$Push = \frac{\sin\ Angle\ * PSI * \pi * (b^2)}{4} \tag{53}$$

Required pull power (foldable plate retreats, helideck opening):

$$Pull = \frac{\sin\ Angle\ * PSI * \pi * (b^2 - d^2)}{4} \tag{54}$$

In the next fig.70 its plots the force of the plate, pushing on the piston and the required piston push force in order to overcome the plate resistance in different angle of attack; and also in the other way around, the resistance of the plate during pulling. On the graph it can be observed that having mainly a high angle of attack, also the required piston power it has to be higher, once the angle decreasing also the required force to push or pull is decreasing until its reaching 0^0(is the condition when the foldable side is perpendicular to the fixed one) afterword's the pressure is reversing.

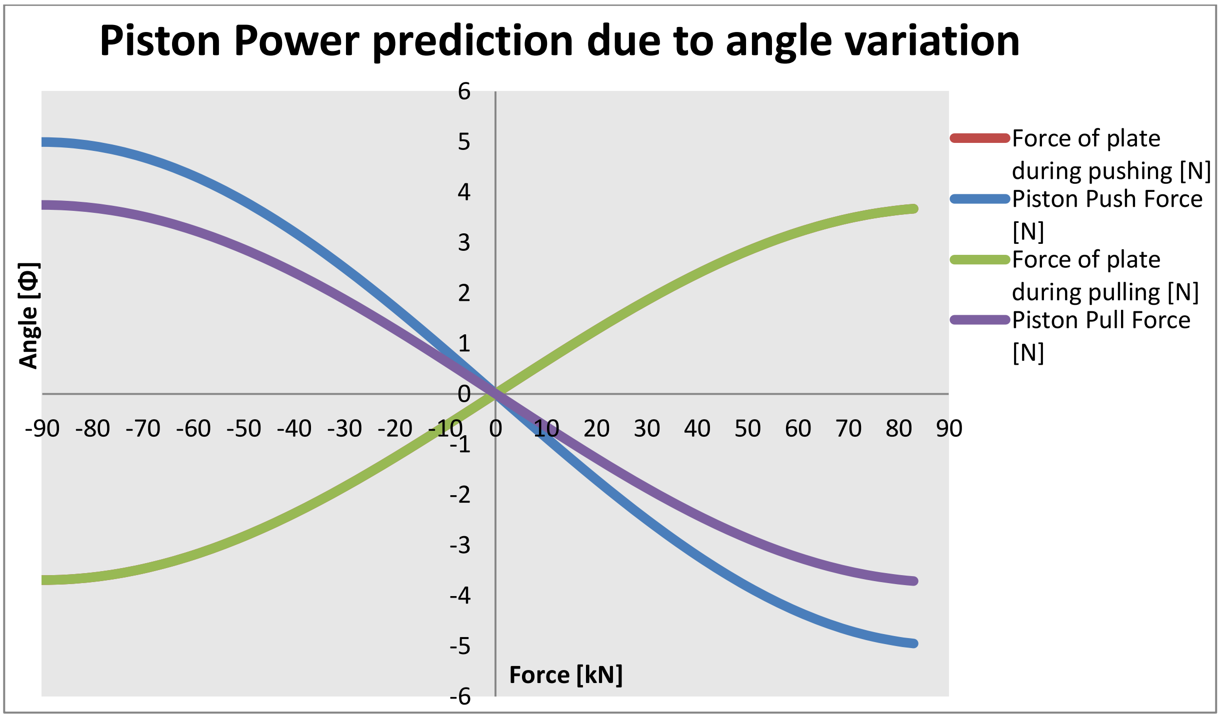

Figure 70. Piston power prediction in function of angle of attack

4.1.2.3. Foldable Mechanism

As it has been showed in the weight assessment section, the biggest foldable side weight is around 800 kg, which means that eventual accidents, likewise the helicopter is hitting this foldable part, the impact could seriously affect the structural instability. Therefore,

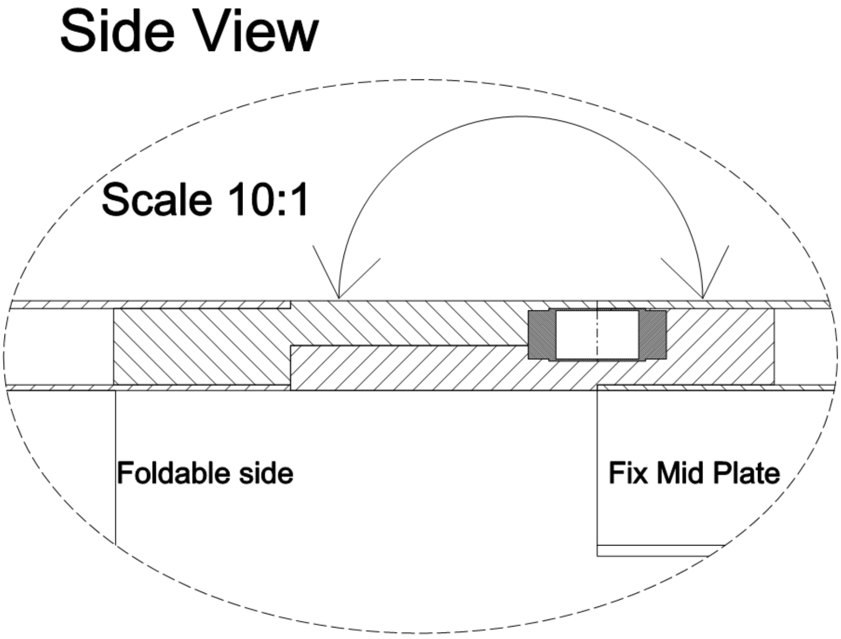

Figure 71. Section view of the folding and fix plates

fig. 71 shows a solution to hinge together the foldable and the fix parts. Note that the solution of the hinges was adopted from other systems, and unfortunately it cannot be found any geometrical description about them, just the main dimensions. The hinge, low hatched area within fig.71, It's small and remarkably strong – locating inside a Ø38mm tube, so that it becomes invisible when is fully closed (see fig.72). The hinge is made from T316 stainless steel with aluminum bronze arms all externally polished.

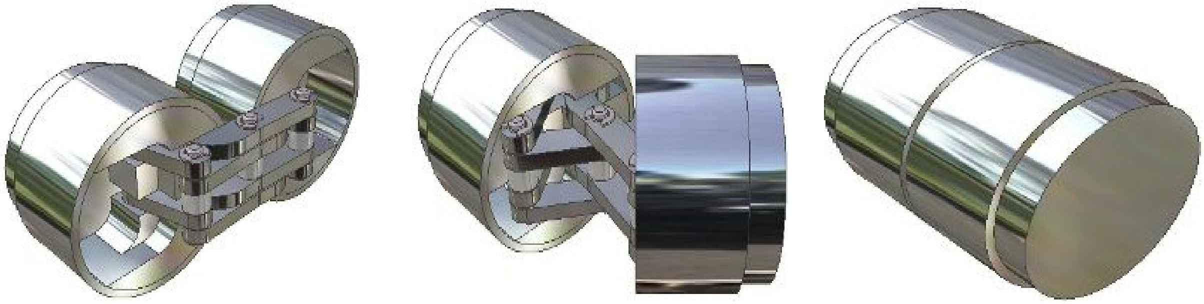

Figure 72. Tube hinge

Furthermore, the effective mechanism is described through fig.73. The plate is folded by two symmetrically distributed hydraulic pistons, every each of them supplied with 13 bars.

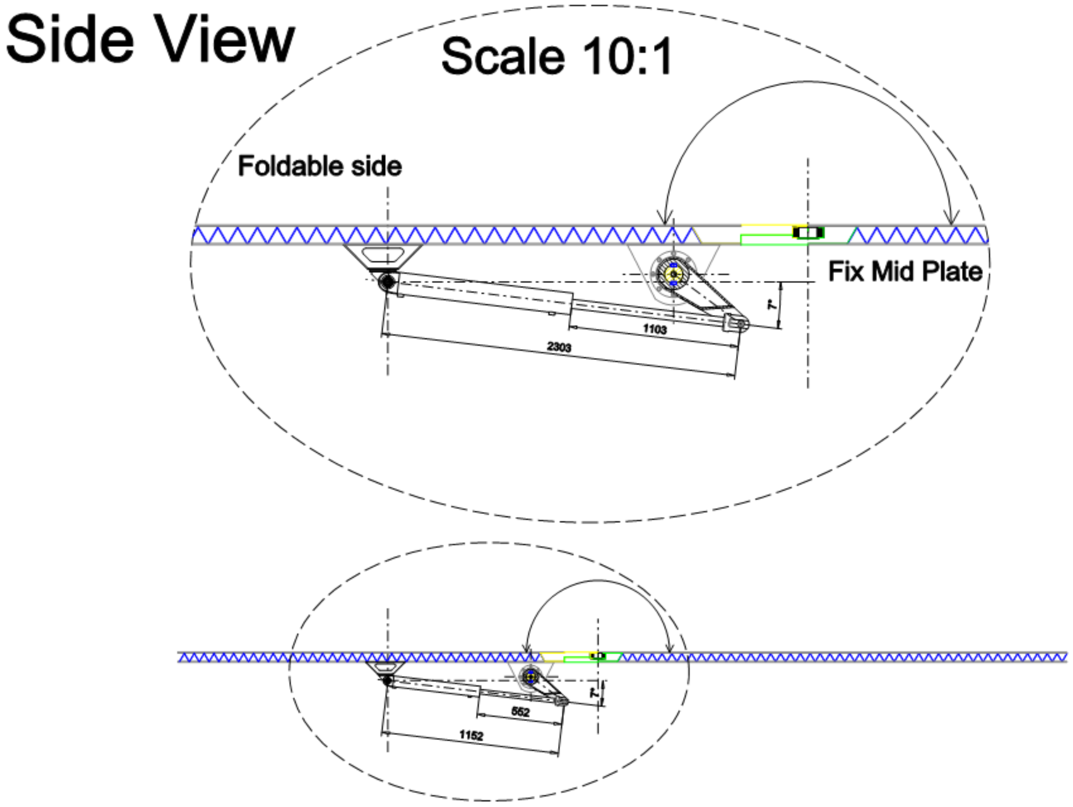

Figure 73. Longitudinal foldable side plate mechanism

The piston is the one obtained after the power and geometrical prediction, is approximately 2 m long. The cylinder during retreating is pulling a mechanical arm which

Furthermore is transferring a rotational moment into the highlighted box, which serves like a reverse gearbox; which role is to reduce the piston translation track, and increase the plate folding speed. The gearbox is composed from 4 main gears, which role is to increase the rotation speed of the plate, and other two which are fixed and receiving the motion from the gearbox, and furthermore transferring it within the fix connection to the plate.

Within this solution a really significant space can be reduced below (when the helideck is open) and above the helideck (when is closed and “stored” in the sundeck’s “housing”).

4.2. Basic outfitting

The following sections outline the requirements for helicopter landing area markings which should be permanently painted on the deck. Plans of the marking arrangements including dimensions should be submitted to the Aviation Inspection Body for approval (surface materials, lighting, marking).

4.2.1. Landing area surface

The landing area should have an overall coating of non-slip material and all markings on the surface of the landing area should be made with the same non-slip materials. Whilst extruded section or grid construction aluminum (or other) decks may incorporate adequate non-slip profiles in their design, it is preferable that they are also coated with a non-slip material unless adequate friction properties have been designed into the construction. It is important that the friction properties exist in all directions. Over-painting friction surfaces on such designs may compromise the friction properties. Recognized surface friction material is available commercially.

Hereby, to accomplish this requirement, the procedure used in the final coating of the given vessel will be used. Usually this procedure it's applied to the side railing of the vessel, considering in here also all the wetted decks (or weather decks), which are in direct contact all the time with either rain or sea- this being a mandatory requirement from safety point of view according to classification societies.

Now to obtain this non-slip surface of the landing area as it was mentioned above the same procedure is used as it was used before on the initial vessel, this procedure being a Spray method.

The material which can be used is Griptex Non Skid, which is a polymer bead aggregate used to provide non-skid deck and step areas when mixed with any Awlgrip topcoat. The mentioned spraying procedure is special and "fragile" method, so it should be carried out carefully in order to fulfill and cover properly the above mentioned requirements and obviously not damage the surface of the landing area.

4.2.2. Visual Aids

The following section outlines the requirements for the helicopter landing area markings, which should be permanently painted on the deck. General arrangement of these, including dimensions should be submitted to the Aviation Inspection Body for approval. This markings and lighting defines the safety operational area limits of the helicopter, called also Safe Landing Area (SLA) for day and night operations.

4.2.2.1. Helicopter Landing Area Markings

Landing area operation line markings were optimized in such a way to offer a good visibility and safety operation, see fig. 74.

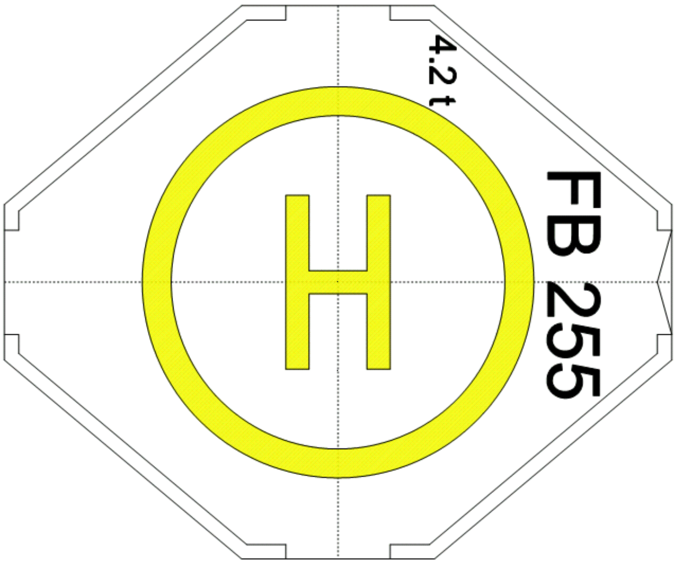

Figure 74. Marking proposal for the FB 255 vessels helideck

The color of this safety markings were chosen in order to be in contrast with the helideck surface, which usually is gray. A detailed sketch of this fig. 74 it's also included in Annex 3.

4.2.2.2. Lighting

The safe landing area (SLA) should be delineated by green perimeter lights visible Omni directionally from on or above the landing area. These lights should be above the level of the deck but should not exceed the height limitations.

4.3. Final structural assessment

This last section represents the helideck final structural assessment. It has been showed within the previous sections the foldable helideck proposal, this being composed from 4 foldable parts, two transvers approximately 1000 mm each and two longitudinally which overall length reaches 2500 mm. These geometrical dimensions for the helidecks foldable parts were obtained due to the small "housing" area available upon the vessels sundeck. As it has been showed these foldable parts are connected, and sustained by solid aluminum extrusions (see the light grey area within fig. 75).

Therefore within this final structural strength assessment, the landing area biggest foldable part will be considered as potential problem. As it has been mentioned it has a length of 2500 mm, and is only caught to the fixed middle plate by the hinges within the solid aluminum extrusion profiles.

Hereby, through a finite element analysis the behavior of the longitudinal foldable plate has been analyzed. The middle fixed plate is considered simply supported (see fig.75, the blue area under the light green solid connection) under its solid aluminum connection profile; the foldable part is considered free.

The virtual model was build up in Siemens Nx commercial 3D software, and for the finite element method Nastran solver was used, incorporated within the Nx software. For the analysis just the half of the landing area has been considered. Within fig.75, the green trapezoidal plate represent the foldable part of the helideck, until the light green solid connection, furthermore the half of the middle fix plate is considered.

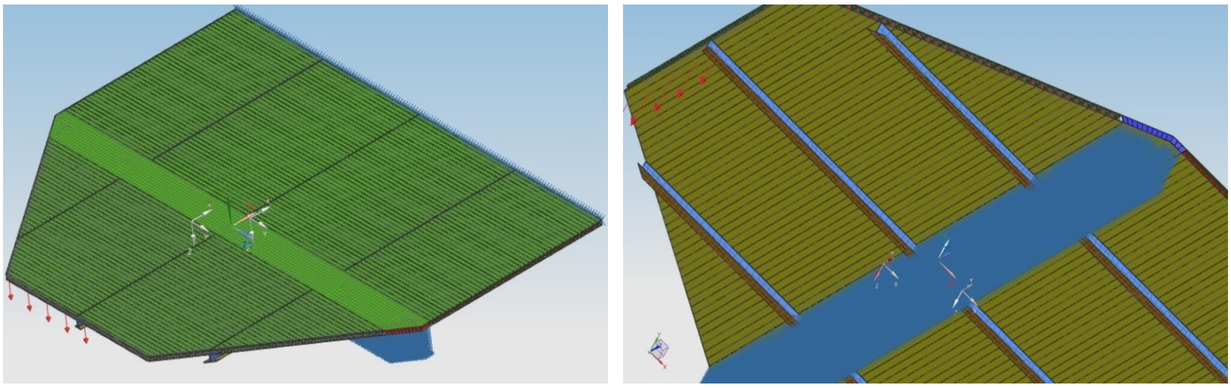

Figure 75. Boundary conditions

The landing area extrusion profiles were modeled using surfaces, in order to save computational time; unlike the solid connection, which was modeled as a solid.

On the symmetry axis of the middle plate was considered fixed, being way far away from the analyzed zone. For the foldable side in this above presented conditions, the worst which he could encounter from a accidentally helicopter landing, could be on its free edge, as is showed with red downstream pointing arrows. On this edge the same condition was applied likewise in the previous structural assessment parts, only in this case just a line force was applied, equal with 45145 N.

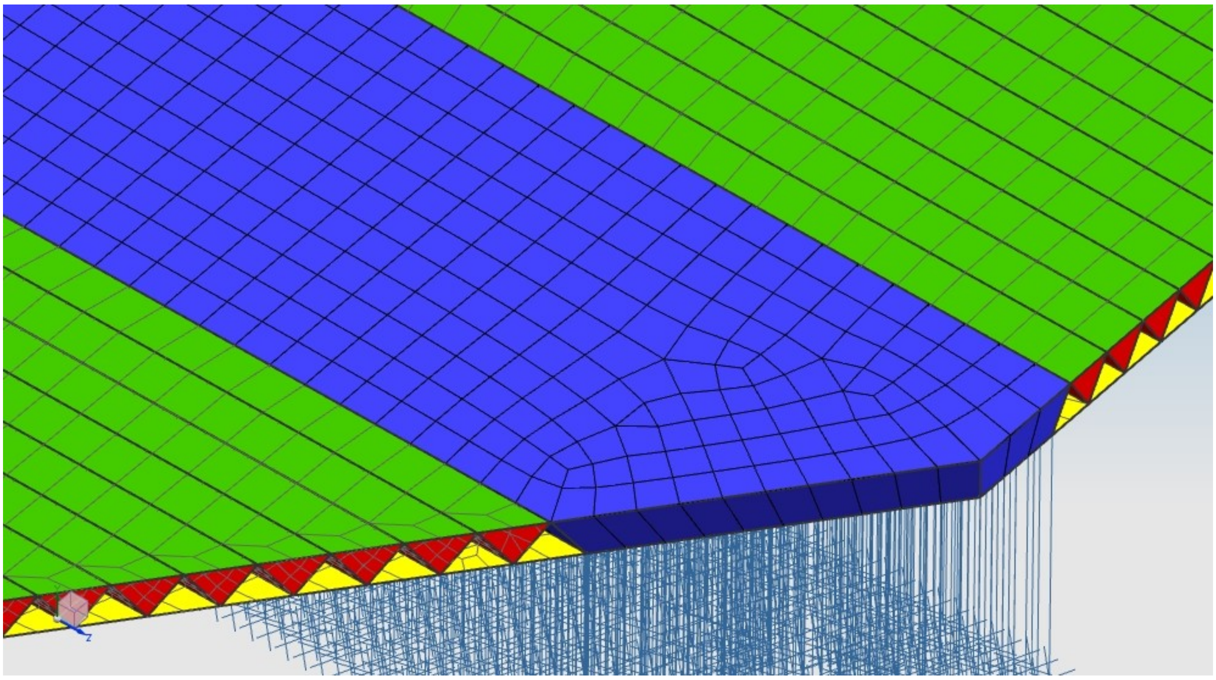

Figure 76. Mesh connections between the shell elements and solid

Further the mesh was applied (see fig.76), using 2D shell elements to construct the surfaces mesh, and Chexahedral 3D mesh was used. During the mesh assessment it was checked the mesh elements outlines, see fig.77. Through this was chased the convergence of the elements, in such a way to get a fluent and high accurate mesh, in order to avoid any structural errors. In fig, 76-77 in can be notice an accurate convergence in between the solid element and the shell elements. The blue solid connections were considered as one, due to the

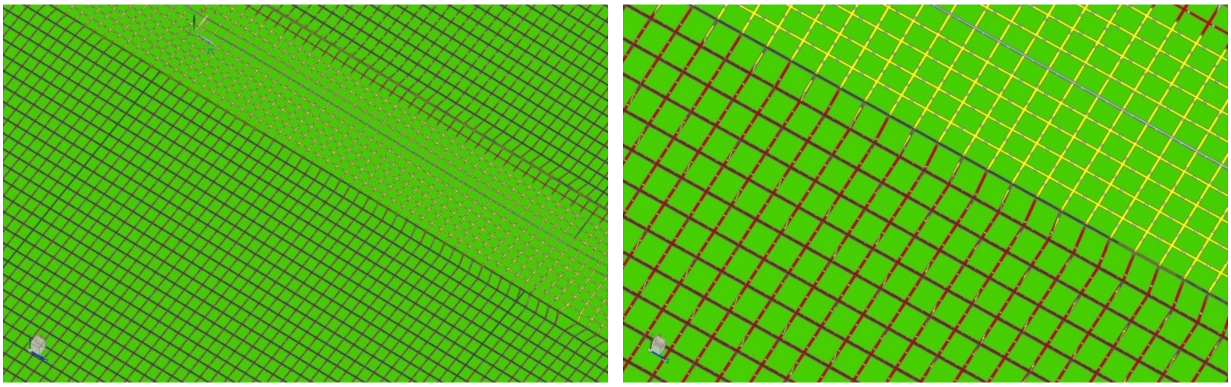

Figure 77.Element outlines

small and sharp corners of their profiles, convergence of the elements couldn't be reached otherwise.

Furthermore the analysis was performed, through fig.78-79 it's highlighted the maximum deflection, which maximum it's reached within 34 mm deflection. But it can be also observed that that the maximum deflection is locally, and due to the really high force applied the structure presence relatively good structural stability. The maximum deflection remains mainly in the aluminum extrusion, the reactions transferred to the stiffeners its relatively small.

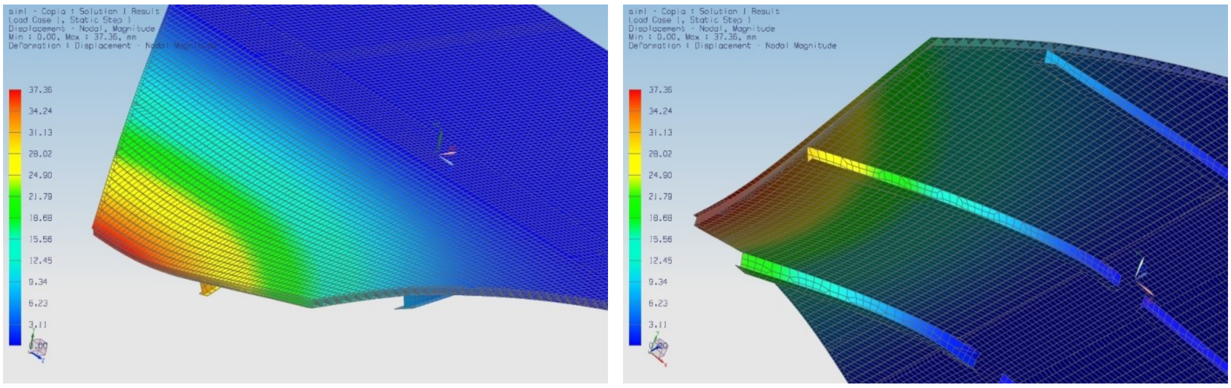

Figure 78. Maximum deflection

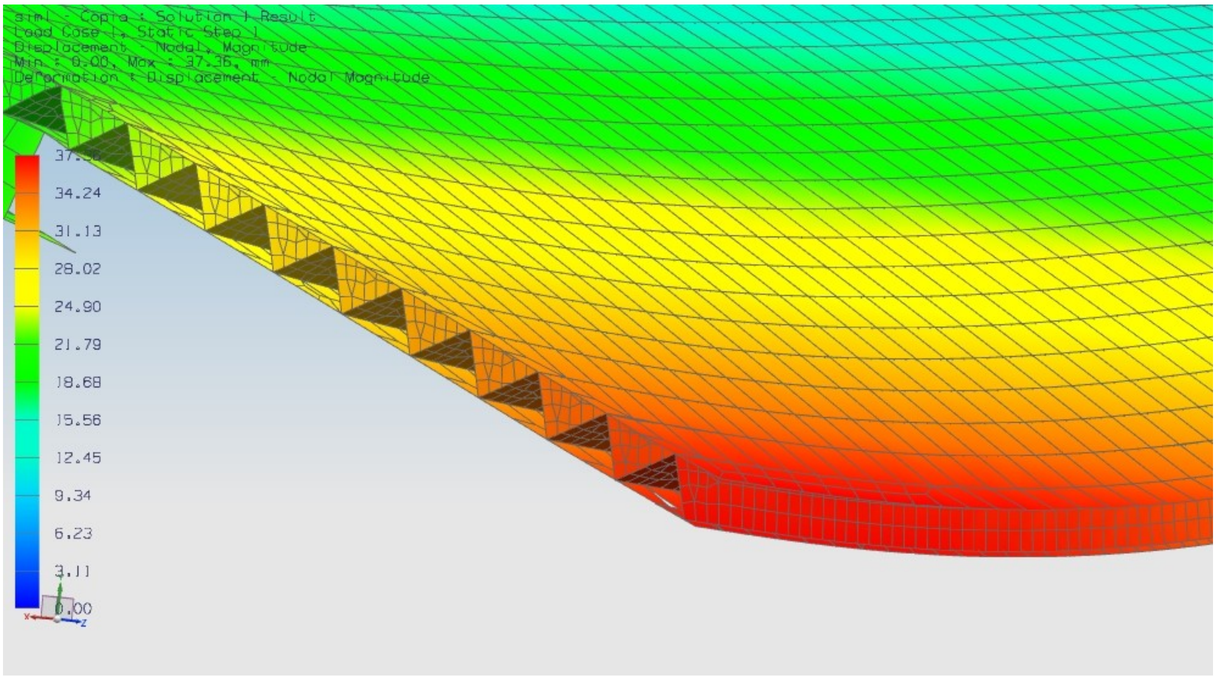

Figure 79. Nodal deflection

The Von-Mises stress distribution is highlighted within in fig. 80. It can be noticed that unlike in the maximum deflection case, the maximum reactions are far away from the loading area; this is probably due the good coo working between the aluminum extrusion and the longitudinal member. It could also happen due to the reaction between the stiffener and the solid extrusion connection, reaching in between this area 80 MPa, which is way below premised stresses. But likewise it could also happen to the sharp edges of the stiffeners web.

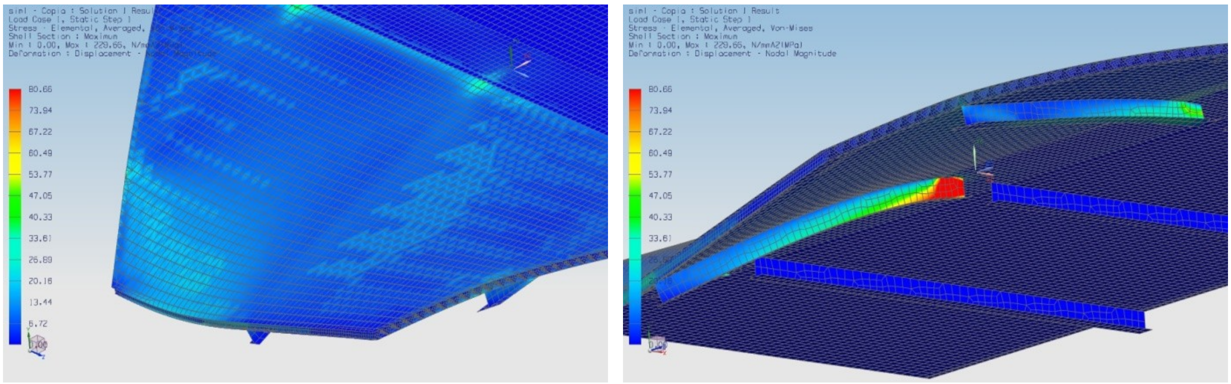

Figure 80. Von Misses stress distribution

Furthermore, shear stress distribution was computed, see fig.81. As it was accepted the maximum shear flow is within the aluminum extrusion skins in the cores, in the centroid od the structure.

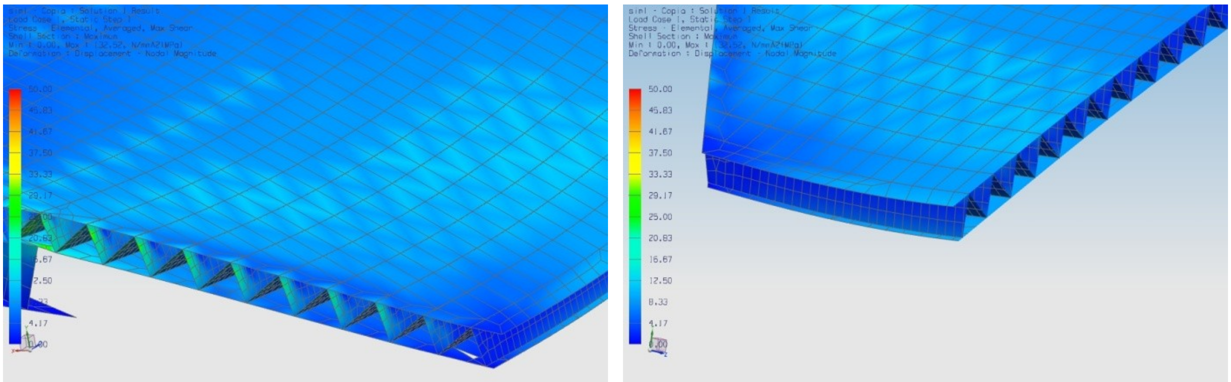

Figure 81. Shear stress distribution

The maximum shear stress is reached around 50 MPa, which is way below the permissible.

It can be noted, that the obtained results are relatively acceptable, but anyhow some structural optimization could be performed, on good approach could be to transfer the induced moments, furthermore on the mid plate stiffeners through some small links.

5. CONCLUSIONS

It has been showed, that having already a given vessel since the initial stage of the research its offering advantages and drawbacks for the design stage of this research. Knowing since the beginning the geometrical size of the vessel it's offering an advantage looking thought the Section 2.2 – Choice of the helicopter, the job is simplified, the geometrical size of the vessel is not giving to many alternatives in choosing of the helicopter, see table 1; for example having a bigger size yacht the alternatives on choosing a helicopter are much more complex, but much less difficulties in fitting it on the board of the vessel. Now, generally speaking the drawback occurs when the new helideck it has to be fitted on board the vessel, having already a restricted relatively small area, the geometrically constraints required by the rules are making the design stage much more difficult that is seems, but for all of this will be related in the following section 4 – Determination of the geometrical constraints – this being imposed strictly and mandatory thought the LY2 code, like safety operational requirement, imposed by the CAA (Civil Aviation Authority).

Eurocopter EC 120 technical properties are simplifying indirectly some critical design issues that other helicopters may induce due to the bigger geometrical dimensions that they offer.

- Being a single engine helicopter, is simplifying the rules requirement, for example safety net is not required (in accordance with Table 1- Section 2.2 - Subsection 2.2.4);
- The size (see fig.7 Subsection 2.2.4) it's giving a small landing area, much easier to be fitted on the vessel-and automatically smaller rotor diameter, which induce less airflow around the vessel;
- The light weight, 1.8 tons (Table 2 – Subsection 2.2.4), which gives less dynamical impact in case of emergency landing consideration – see structural assessment Chapter;
- Small size, but capable to transport 5 passengers.

Furthermore it has been showed that structural assessment it's a difficult design key, the complexity being given by the worst landing condition, which can induce really high structural instabilities.

Within the aluminum extrusion profiles it was possible to reduce significantly any structural problems, they showing a high structural strength in both its directions. Another important, and maybe the most important one, light weight, showing approximately half weight reduction comparing with normal aluminum plates.

The foldable mechanism solutions, shows relatively good agreement, simple construction, and can even be fitted really easily with yacht and helideck aesthetic. Anyhow for further considerations it should be taken in account some optimizations upon it.

FUTURE CONSIDERATIONS

Mechanical design

Furthermore a mechanical design shall be consider in order make the linkage between the landing area “housing” and the effective position during a requested landing. To do this, this research shall be briefly reviewed..

Environmental assessment

The safety of helicopter flight operations can be seriously degraded by environmental effects that may be present around vessels. The term “environmental effects” describes the effects of the vessel, its systems, and forces in the surrounding environment, which result in a degraded local environment in which the helicopter is expected to operate. These environmental effects are typified by structure-induced turbulence, and turbulence / thermal effects caused by exhaust emissions. Controls in the form of landing area availability restrictions may be necessary and should be imposed via the Aviation Inspection Body. Such restrictions can be minimized by careful attention to the design and layout of the vessel topsides and, in particular, the location of the helicopter landing area.

Yacht safety assessment

This task it’s required after accomplishing the above suggested ones. This task includes a intact and minor damage (vessel less than 85 m) stability test.

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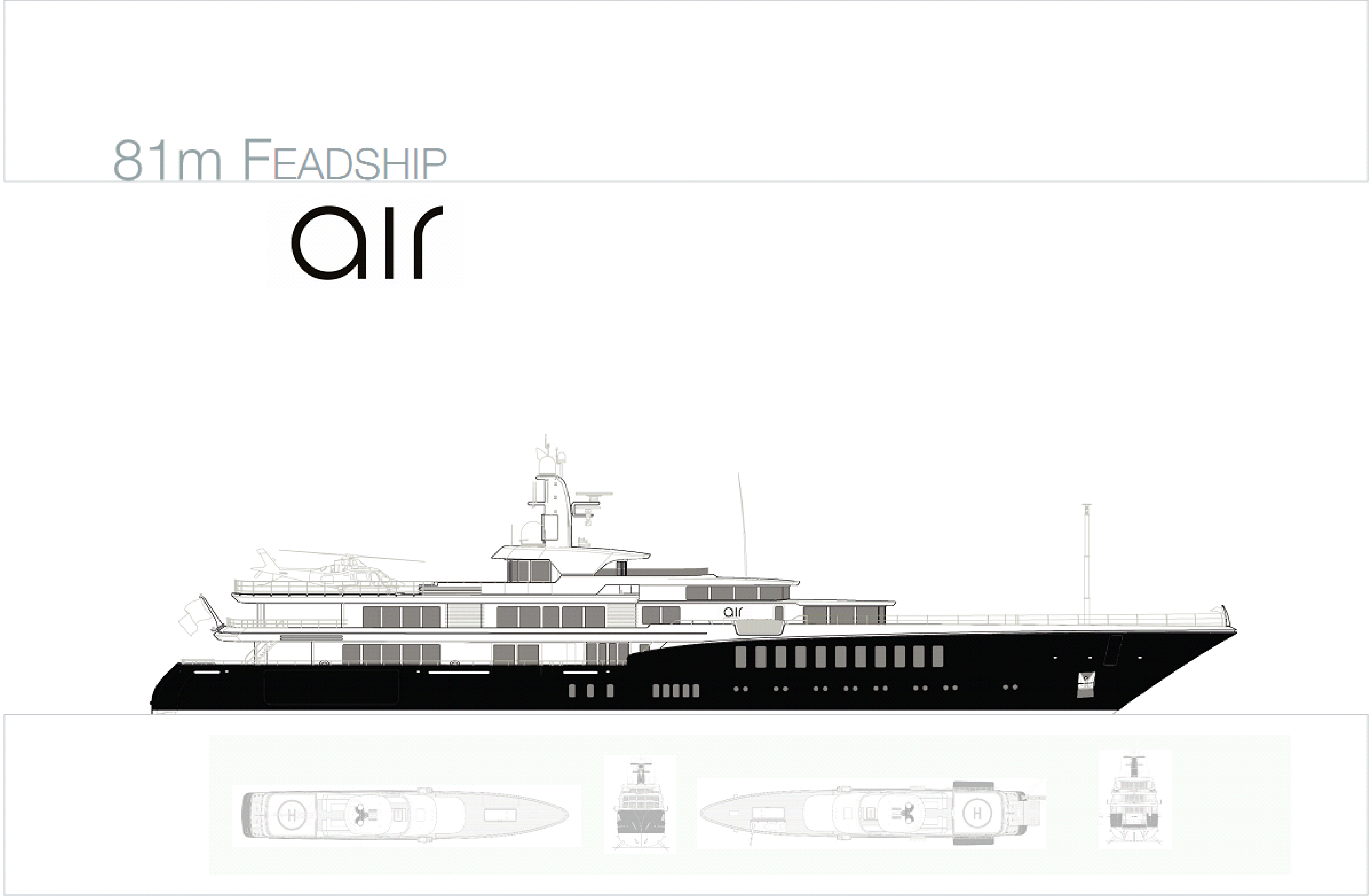
	Seung Il Seal, Keon Ho Sonl, *A Study on the Application of Large Aluminum Hollow. Extrusion Profiles to Ship Structures.*
	Martin Hager, *Touchdown for dinner*, Heli-special

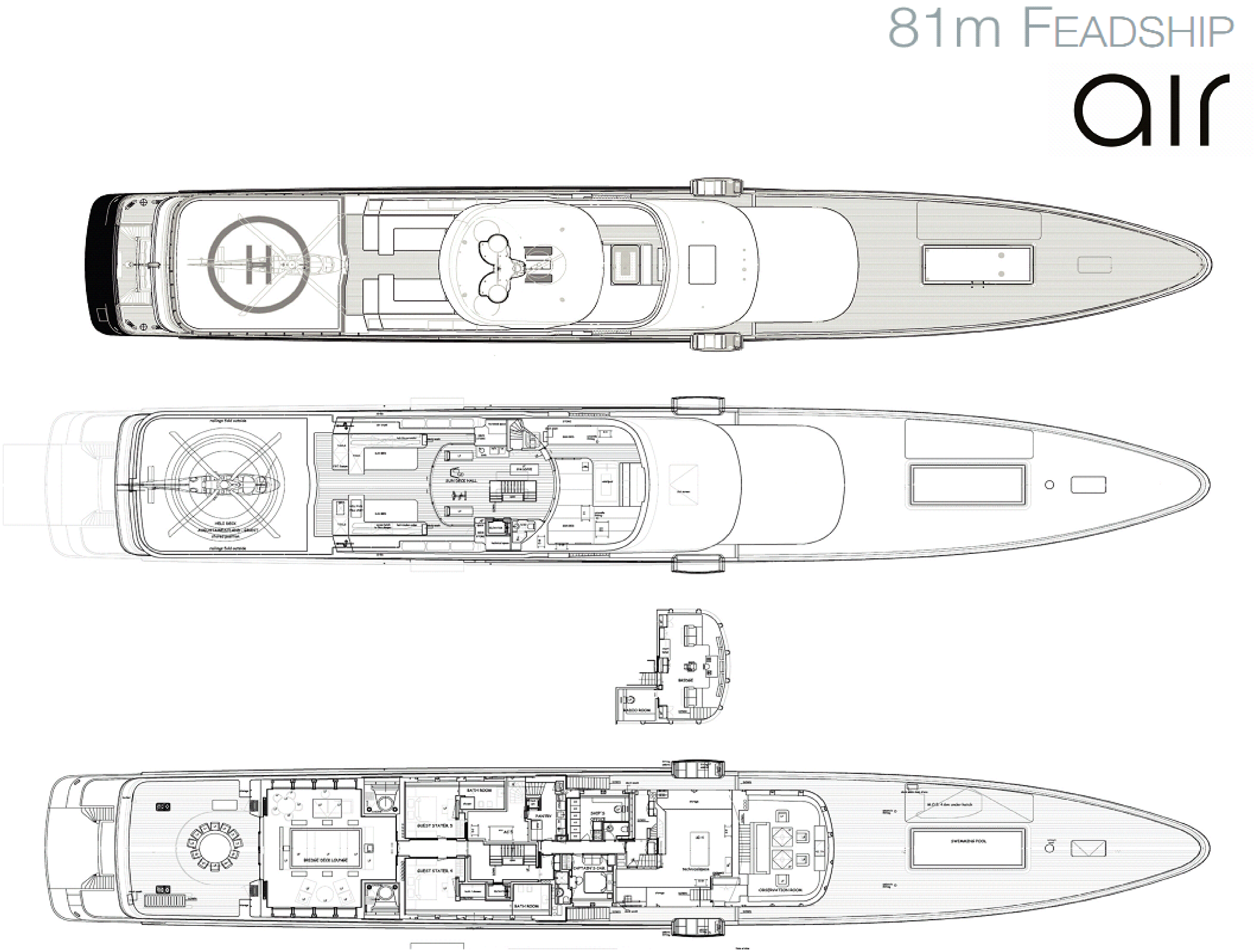
APPENDICES

ANNEX 1 Description of the 81m Motor Yacht AIR

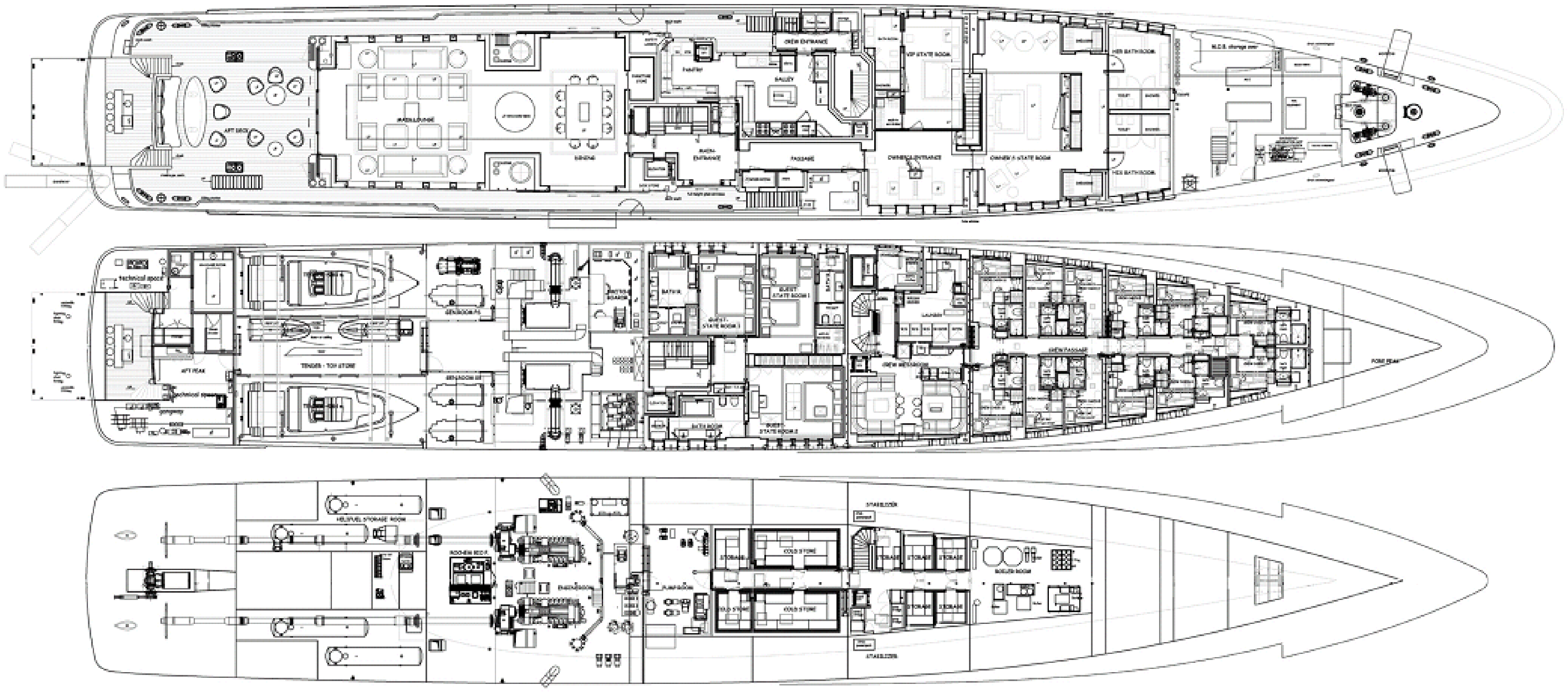
Section 1 - Side view of the 81m Motor Yacht AIR



Section 2 - Top view of the 81m Motor Yacht AIR



Section 3 - General arrangement - Top view of the 81m Motor Yacht AIR



Available for limited exclusive charter

LOA	81 metres
LWL	72.6 metres
Beam	11.6 metres
Draught	3.55 metres
Gross Tonnage	1,700 tons
Guest Accomodations	14 in 6 cabins
Crew Accomodations	20 in 12 cabins, plus captain
Propulsion	2 x MTU 16V 4000 M60 1,760kw at 1,800 rpm
Propellors	5 blade Wartsila
Shafts	Akerboom Oil Bath
Gearboxes	Reinjes WAF 863L
Stern	Thruster Van de Velden 1050 EPS - 320kw
Speed (Max/Cruise)	17 knots / 15 knots
Fuel Capacity	177,000 litres
Heli Fuel Capacity	15,480 litres
Range	5,000nm
Power Generation	3 x C18 Caterpillar - 350kw 1 x C9 Caterpillar - 250kw
Emergency Power	125 EFOZD Kohler - 125kw
Stabilisers	2 x Quantum XT Zero Speed
Bowthruster	Van de Velden 250kw
Windlasses	Muir
Watermakers	2 x HEM H40 Duplex - 39,000 litres / day
Shore Power Converters	4 x AC 75V ASEA
Monitoring System	Imtech AMCS
Electrical	Imtech
Fire Detection	Tyco
Fire Suppression	Marioff Hi-Fog
Security System	Imtech CCTV 3500 with DACS
Audio Visual System	Kalidescape controlled by Iphone and Ipad
Construction	Steel hull, aluminium superstructure
Classification	Lloyds Maltese Cross 100A1-SSC Yacht (p) Mono, G6 LMC, UMS
Interior Design	Remi Tessier Design
Exterior Design	De Voogts
Naval Architecture	De Voogts
Engineering Design	De Vries / De Voogts
Builder / Year	Koninklijke de Vries Scheepsbouw 2011

ANNEX 2 Technical Specifications on BENETTI FB255, 60 m, Steel and Aluminum

Section 1 –Technical specifications

00.10 General information

00.10.01 General

The vessel described in this specification is a motor yacht with a displacement hull equipped with two diesel engines, tw0 propellers, two spade type rudders and one bow thruster.

The hull will be built in steel while superstructure will be built in aluminum alloy.

This specification is correlated:

To the General Arrangement plan FB255-101-02-01 rel.03 dated 28/02/2011 for the general aspects and accommodation layout.

To the Book Excellence for the quality standard of interior supplies (fixed or loose).

To the "Functional Plans" for the amount of supplies.

To the Benetti Standard LIB for the building detail and the workmanship.

The yacht will be designed as a luxury yacht for world-wide cruising excluding ice zones, for use privately by the Owner as well as for commercial charter.

Charter capacity is restricted to 12 passengers according to Flag State authority's regulations.

00.10.02 Parties

The Builder:	Azimut-Benetti S.p.A.
Interior designer for Owner's area and guest areas:	to be appointed by the Buyer and paid by the Buyer.
Interior designer for crew accommodation and service areas:	Azimut-Benetti S.p.A.

Designer for all external areas:	Azimut -Benetti S.p.A.
Naval Architect:	Azimut-Benetti S.p.A.
Stability:	Azimut -Benetti S.p.A.
Hull hydrodynamics design: Classification Society:	Azimut -Benetti S.p.A. American Bureau of shipping
Flag State Authority:	Red Ensign.

00.20 DESIGN AND PERFORMANCES

00.20.01 Main Characteristics

Length overall:	60.00 m – 196' 10"
Length waterline at full load:	52.4m – 171' 11"
Overall beam:	10.60 m – 34' 9"
Draft at full load from underside of keel:	3.37 m – 11' 1" about
Total fresh water capacity:	20,000 Litres – 5,283 US Gallons about
Total fuel capacity:	115,000 Litres – 30,379 US Gallons about

Internal net heights, between rough floor and finished ceilings, will be in accordance with the attached "functional plan" (TAV. 07).

It is to be noted that the yacht is custom built and therefore the above mentioned hull dimensions and tank capacities may be subject to minor reasonable variations.

Any significant deviation from the above technical data will be notified to the Owner's Representative.

00.20.02 Hull design, stability

Hull will be designed on the basis of experience on previous similar vessels, for the yacht to have the appropriate sea keeping, maneuverability and general handling characteristics.

Tank test will be performed if necessary according to Builder's experience to verify the predicted performances.

A stability test will be carried out in order to determine the position of the center of gravity and to determine that the yacht's stability is in accordance with the Flag State authority's and Classification society's stability parameters.

A stability booklet containing the stability characteristics of the yacht under various load conditions will be prepared according to the Flag State authorities and the Classification Society's requirements.

Owner's supplies of up to 12 metric tons will be considered in the stability book. These include tenders and water sports toys, cutlery, glass, Object d'art, spares (excluding those spares required by the Classification Society and Flag State authority), etc.

Additional weight may cause an alteration of the yacht's performance or may be deducted from fuel or water capacity. Vertical position of these weights may lead to the need of adding ballast. This ballast will be deducted from yacht deadweight.

00.20.03 Performances

Max speed, at half load condition:	16 knots.
Cruise speed, at half load condition, at 85% MCR:	15 knots.
Range at 12 knots calculated at half load	
displacement, using two engines and, one generator working:	5,000 nautical miles.

The above performances will be tested during Sea-Trials.

It should be noted that all power, speed and range figures specified are based on a maximum outside ambient air temperature of 35°C and a maximum water temperature of 32°C. Higher air and/or water temperatures may result in a reduction.

The following items have been considered for the definition of half and consequently the half load displacement for autonomy:

Owner' s supplies (within the specified allowance 00.20.02)
Owner, Guest and Crew effects and baggage(3.5 t)
Provisions & stores (50% of 3t)
Fuel Oil (50% of the fuel strictly necessary for the range)
Fresh water (50% of contractual capacity)
Lub. Oil (50% for the capacity)

00.20.04 Noise and vibrations

A complete study of noise and vibration will be conducted and maximum care will be taken to control noise and vibration levels in any operating condition of the yacht. Noise levels will be tested in the following conditions:

Cruise speed 15 knots, with one generator running and air conditioning on (primary air and fan coils at medium speed) and all doors closed.

At anchor with one generator running and air conditioning on (primary air and fan coils at medium speed) and all doors closed.

Noise levels are to be measured according to ISO2923 in the center of the compartment or area at 1,2 m and 1,6 m meter above the floor or deck.

The following average levels, measured in dB(A), will not be exceeded in the mentioned conditions: (a tolerance of +/-1 dB(A) will be accepted).

Area – Room	Crusing speed	At anchor
Crew cabins	60	50
Crew mess	60	50
Main galley (exhaust fan at low speed)	60	55
Guest cabins Lower Deck forward	54	48
Guest cabins aft Lower Deck	58	48
Owner's suite	52	48
Main dining room	58	48

Main deck saloon	60	48
Upper deck saloon	58	48
Upper deck VIP Cabin	56	48
Captain's cabin	55	48
Wheelhouse	56	48
Control Room	80	70
Exterior main deck aft	80	55
Exterior bridge deck aft	70	55
Sun deck middle	65	55

In the Owner's and guest interior luxury areas and crew accommodations vibration levels are not to exceed a peak velocity of 2mm per second and in any other compartment or area of the yacht the measured value shall not exceed ISO6954 1984 (E).

The type and characteristics of the sound insulation will be determined on the basis of accurate calculations made to reduce the noise levels (both airborne and structural borne) to the contractual values.

00.20.05 Standard and workmanship

All the materials used and works carried out shall conform with the best luxury yacht building standards. All materials and equipment used in the construction of the yacht will be new, of best marine quality and suitable for the use to which they will be put.

All equipment foundations, piping brackets, ducting brackets and cable tray brackets will be attached to the yacht's structural members and not to the hull shell plating, bulkhead plating or partition paneling.

During the entire construction of the yacht all indicated scantlings and thickness, as well as all equipment specifications will be strictly observed in order to control the weight.

The Builder will choose materials and equipment from a List of suitable manufacturers. The List will be delivered to the Owner's Representative before the signature of the contract.

All equipment not specifically named will be chosen from the Builder's library or from the Manufacturer's list.

All the wood used on board will be of excellent quality; the wood must be sound dry and free from cracks, and other defects.

The layout and installation of all machinery, accessories and equipment will allow easy access for routine maintenance and servicing.

00.20.06 Weight control

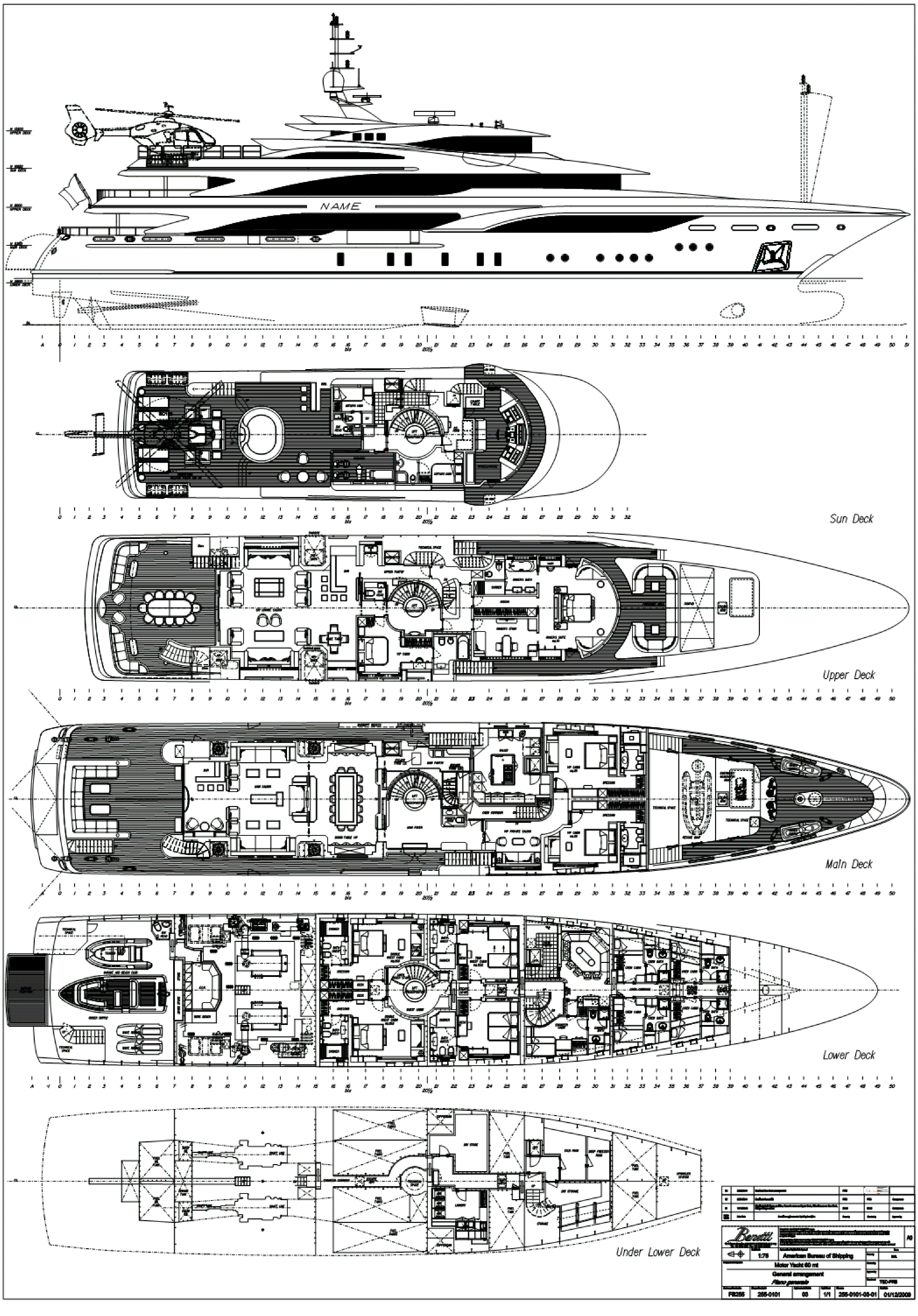
During the entire construction of the yacht all indicated scantling and thickness, as well as all equipment specifications will be strictly monitored in order to control the weight.

The designer shall keep the weights of interior to a minimum compatible with the decoration concepts expressed in the specification.

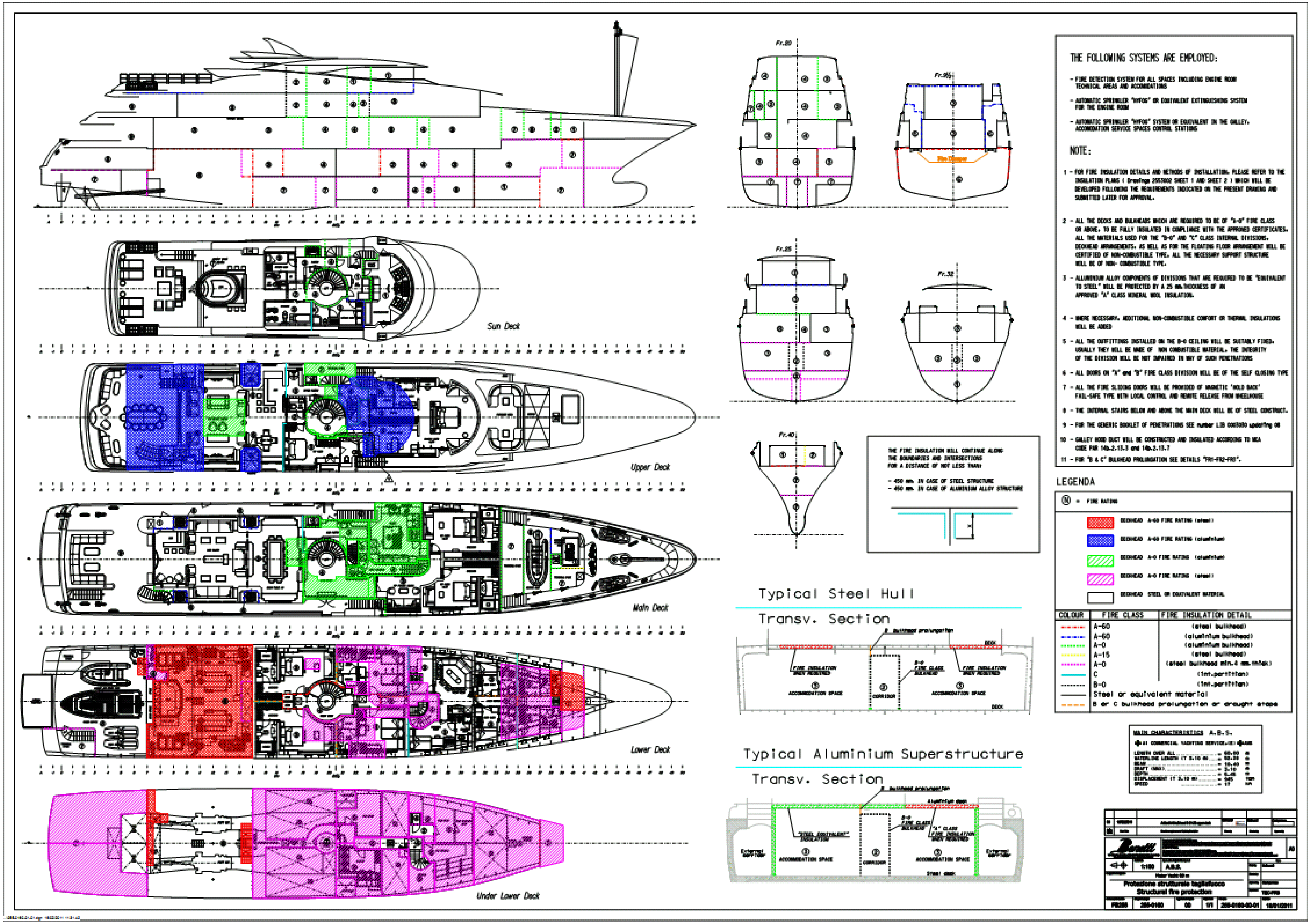
00.20.08 Rules and Regulations

The yacht will be built in accordance with the " ABS rules for building and classing motor pleasure yachts" and will be eligible for the following notations:

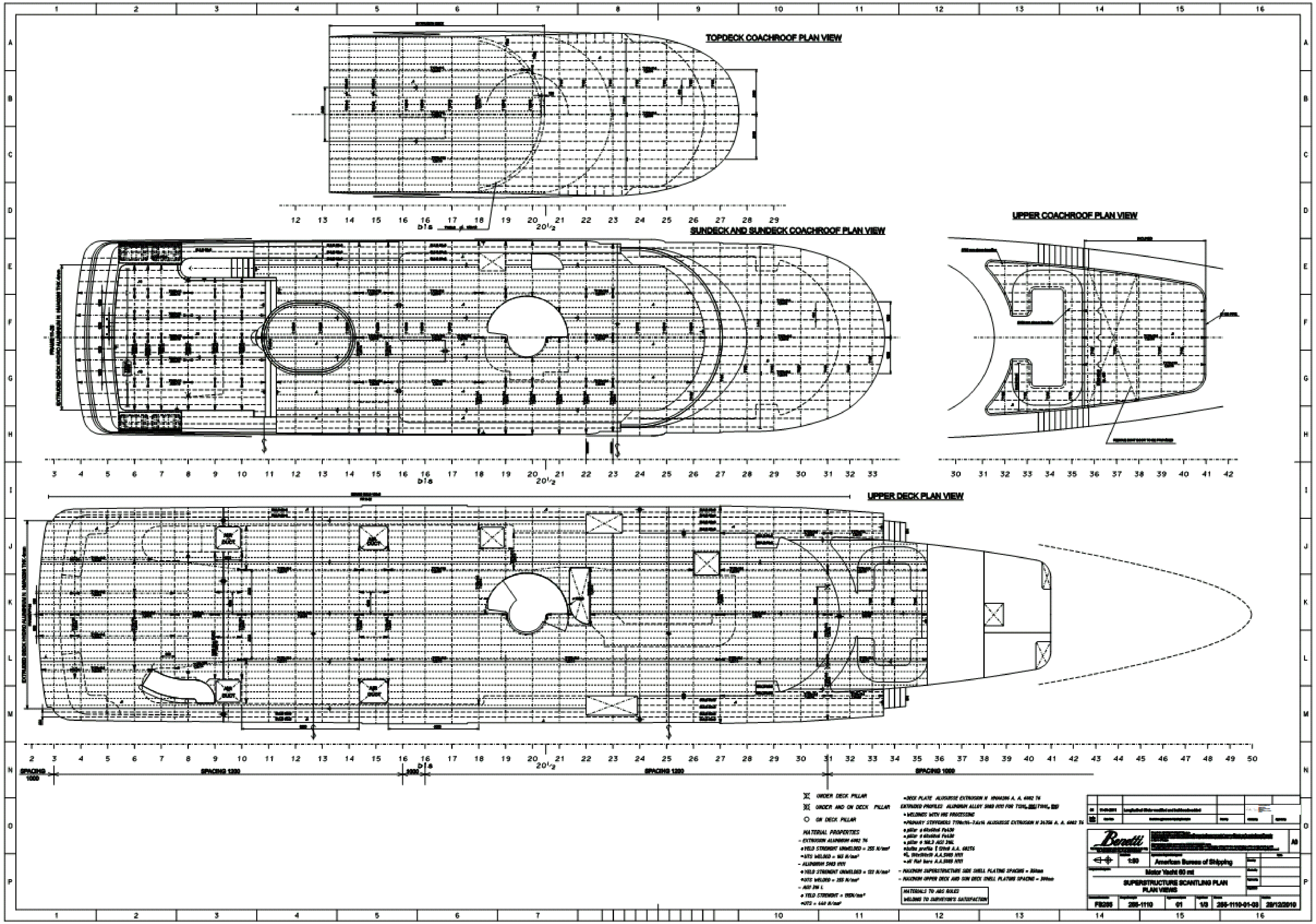
Section 2 –General arrangement

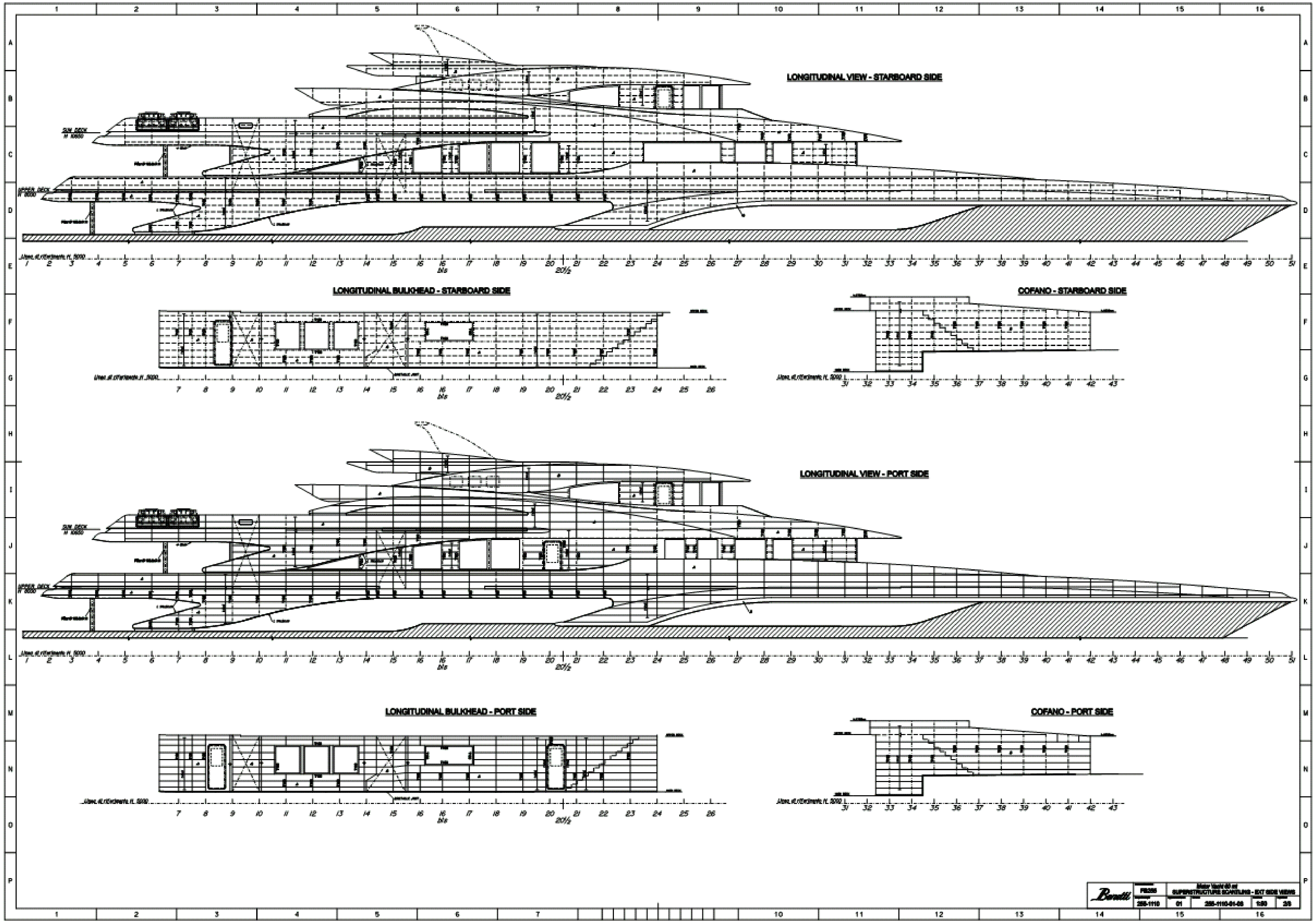


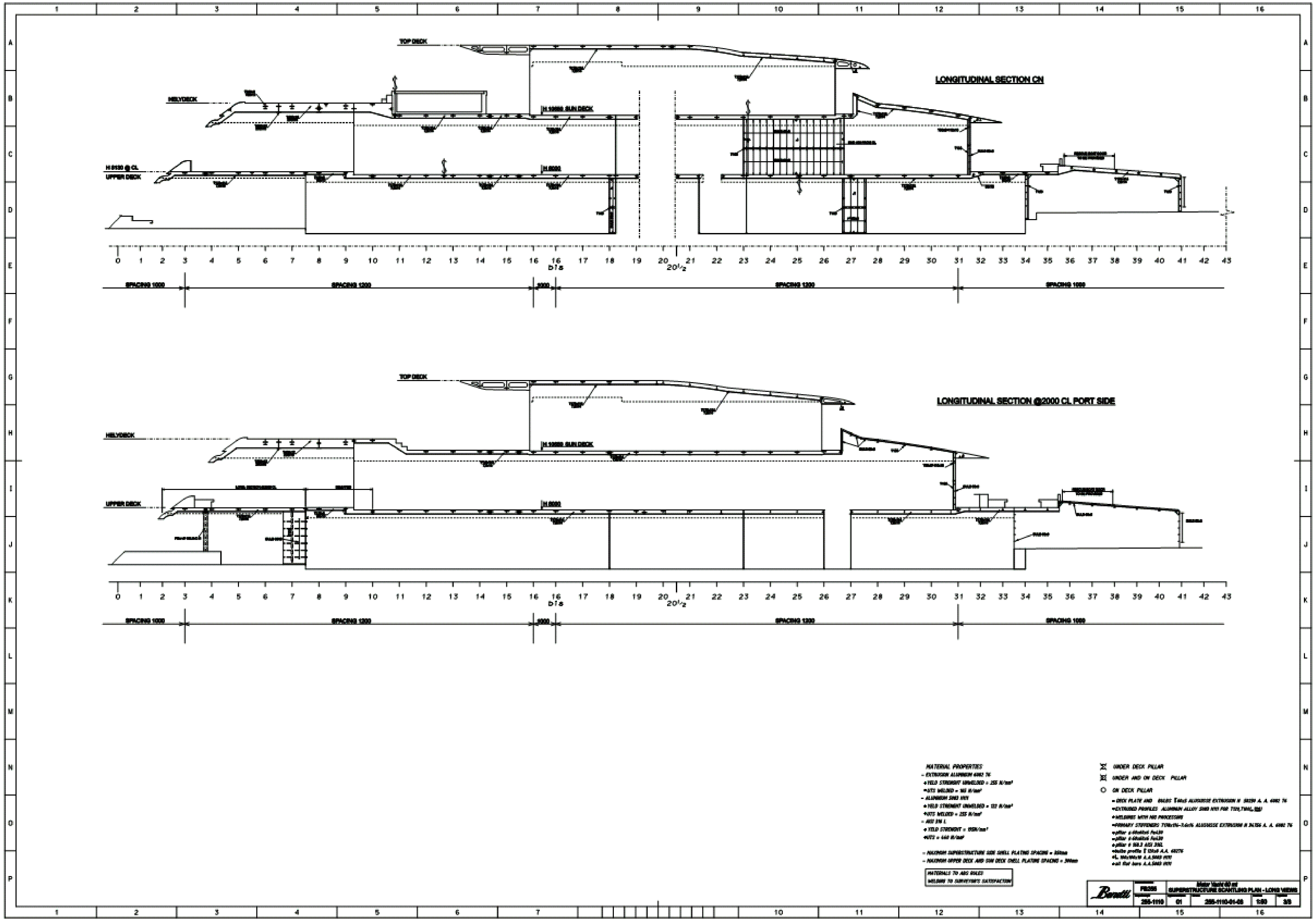
Section 3 –Structural safety



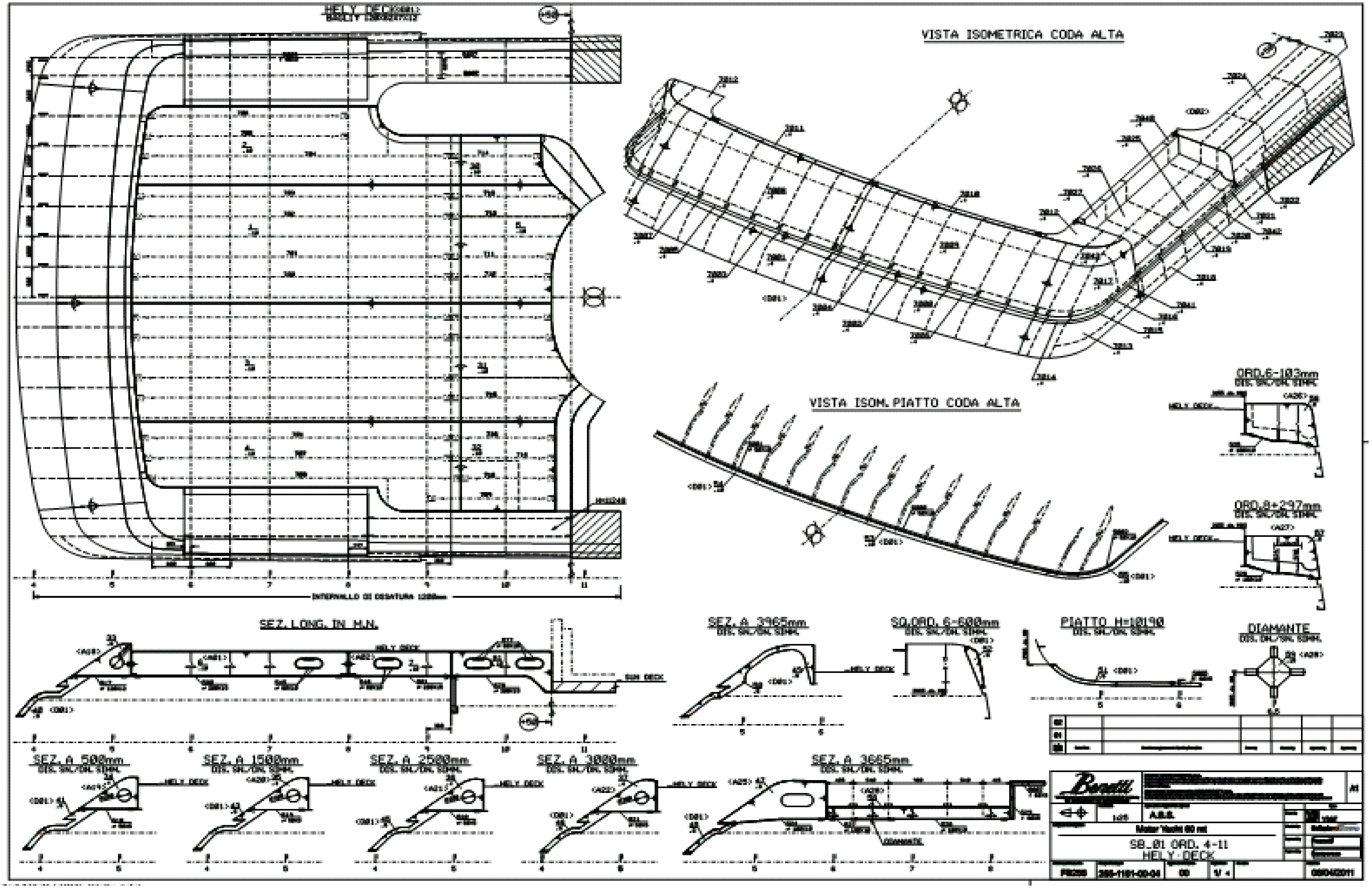
Section 4 –Scantling general overview

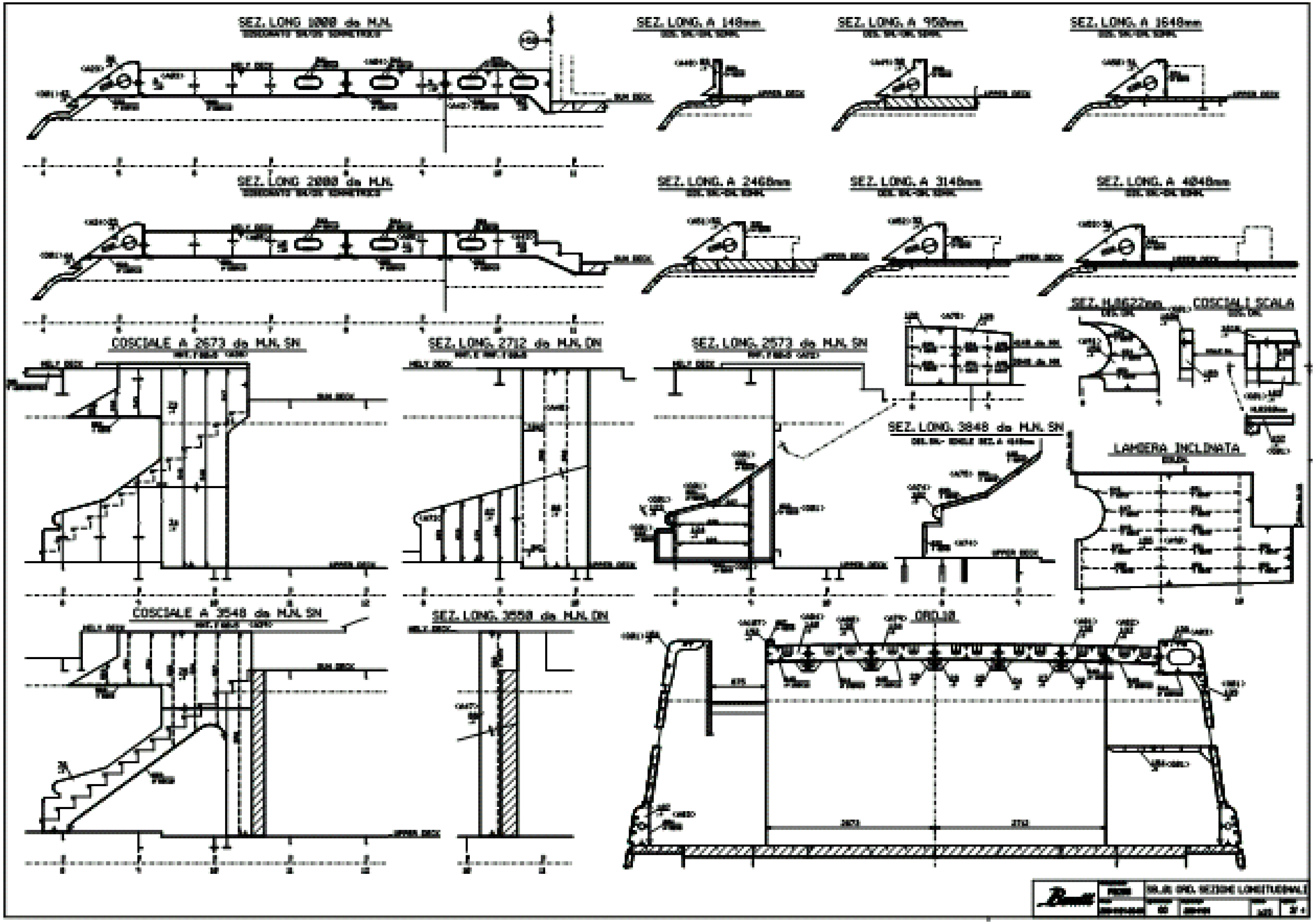



LONGITUDINAL VIEW - STARBOARD SIDE
LONGITUDINAL BULKHEAD - STARBOARD SIDE
COFANO - STARBOARD SIDE
LONGITUDINAL VIEW - PORT SIDE
LONGITUDINAL BULKHEAD - PORT SIDE
COFANO - PORT SIDE
SUN DECK
UPPER DECK
SUPERSTRUCTURE SCANTLING - EXT SIDE VIEWS
255-1110
01
1:50


LONGITUDINAL SECTION CN
TOP DECK
HELYDECK
SUN DECK
UPPER DECK
SPACING 1000
SPACING 1200
1000
SPACING 1200
SPACING 1000
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43
20 1/2
LONGITUDINAL SECTION @2000 CL PORT SIDE
TOP DECK
HELYDECK
SUN DECK
UPPER DECK
SPACING 1000
SPACING 1200
1000
SPACING 1200
SPACING 1000
MATERIAL PROPERTIES
MATERIALS TO ABS RULES
WELDING TO SURVEYOR'S SATISFACTION
UNDER DECK PILLAR
UNDER AND ON DECK PILLAR
ON DECK PILLAR
Benetti
FB255
SUPERSTRUCTURE SCANTLING PLAN - LONG VIEWS
255-1110
01
1:50
3/3

Section 5 –Scantling of the initial sundeck




SEZ. LONG 1000 da M.N.
SEZ. LONG. A 140mm
SEZ. LONG. A 950mm
SEZ. LONG. A 1640mm
SEZ. LONG 2000 da M.N.
SEZ. LONG. A 2460mm
SEZ. LONG. A 3140mm
SEZ. LONG. A 4040mm
SEZ. H 8622mm
COSCIALI SCALA
COSCIALE A 2673 da M.N. SN
SEZ. LONG. 2712 da M.N. DN
SEZ. LONG. 2573 da M.N. SN
SEZ. LONG. 3840 da M.N. SN
LAMIERA INCLINATA
COSCIALE A 3548 da M.N. SN
SEZ. LONG. 3550 da M.N. DN
ORD.18
HELY DECK
SUN DECK
UPPER DECK
2673
2712

ANNEX 3 Helicopter landing area safety assessment and general considerations