SUMMARY

The offshore industry has a big opportunity for improvement in design and the use of other materials. The specific problem in weight, maintenance for the Living Quarters (LQ) and the time-consuming construction method asks for improvement. This report is a feasibility study that will give tools and ideas how to improve these specific problems. The idea of a sandwich panel that can be easily mounted in the structural frame, the specific weight and the idea that its maintenance free will even result in cost-saving.

For the skeleton three materials are investigated; steel, aluminium and FRP. Because of weight saving the need for maintenance and the connection possibility, steel is in a weaker position than the remaining two materials. The great advantage of aluminium and FRP is the large range of profiles. Because of their production process (extrusion, pultrusion) every kind of profile is possibly. A connection profile or rails can be included in the construction profile and need for welding or bolting afterwards can in this way be reduced. A disadvantage is that the E-modules is lower than of steel and profiles must be covered with insulation from the outside to meet the fire-rating. However, for aluminium new tests are being performed to prove there resistance to fire. The problem is that the offshore rules are written for steel but are used for aluminium (and even FRP) to.

Because there is chosen for a sandwich panel, different kind of insulation can be used. This brings a lot of variety in application. Nowadays each project made of FRP (only a few) is certified separately, resulting in a lot of costs. By the realisation of a standard element, certifying of the panel can be done easier, only ones. However the certifying process is slow, a strong convincing power is needed and rules must be adapted or even new rules must be written. The challenge is to find the right composition for a panel that fulfils the following requirements; sound reduction, fire resistance, thermal behaviour and strength. Choosing the right production method can bring a certain speed in process and thereby cost-saving. For the LQ itself a new ‘smart’ module is introduced; the ‘smart’ module. The idea is to have an small module that together with other (small) modules form a large LQ. The advantage is that modules can be easily disconnected and transported to another platform. Because of the limited size a new ‘clean’ continuous production process can be realised.

For this new concept three scenarios are described. A skeleton filled with FRP panels, secondly structural panels and the last of a monocoque system. The first is chosen for different reasons. As described before certification of the panels can be done easier. In-house knowledge and machines (of Hertel) can be used for the skeleton and (purchased) sandwich panels can be placed by their own personnel. When a panel is damaged (by lifting, transport or in place) it can be easily replaced, which cannot be done in the other two scenarios. Knowledge of FRP is still investigated and therefore it is chosen to introduce this material step by step, starting with scenario one.

The sandwich elements can be used for large or small constructions. In this report small modules are chosen which can be connected together and form a large LQ. To fulfil in the client wishes modules can be added or removed to change the quantity of persons on board (POB). Nowadays when personal is needed small stand-alone modules are placed somewhere on the platform totally disconnected from the existing LQ. The modules described in this report have the possibility to be connected and form part of the LQ. The module is sized so different functions can be placed in that specific surface area. Another advantage is that the modules can be built in a clean environment in a reproduction process.

When comparing the transport route of several small modules or one large module (LQ), cost-saving is minimal (Euro 190.000 versus Euro 170.000). At first the transport of small modules brings effort because trucks can be used and small cranes. However the hook-up on the platform can result in high costs. The transport on the island itself is the problem, the LQ is not in the neighbourhood of the platform crane and therefore a lot of obstacles have to be taken on the way. When introducing this small module also the (way of thinking of
the) platform design must change. When the LQ can be placed in the direct platform radius and the area is obstacle free, hook-up can be easily done and therefore reduce the costs.

To save weight and fulfil in the functional requirements the roof and longitudinal walls are taken out. Out of structural calculation, deformation is the critical factor over the stresses that will occur. Therefore floor panels are dimensioned thicker than for the wall panels to increase the stiffness. For stability temporary strips are used (mainly for lifting and transport). The skeleton consists of an extruded aluminium profile with an integrated clamp system.

After a study for the skeleton the main focus is switched to the facade element. The element should have good performance for: fire, acoustic and thermally, strength, maintenance free and blast resistant. The specific composition of different layers (materials) is as following (form inside to outside): FRP-A60Insulation-FRP-SoundMat-Airgap (could be filled with acoustic insulation)-FRP. In case of an explosion the outer layer should be flexible (like a sheeting) absorbing the enormous force in the empty space (cavity) behind.

After research and design a prototype is made. The prototype consists of an aluminium frame and a composite panel. The frame consist of square tubes with the clamp profile included. The panel itself is made of a structural sandwich panel, an air gap and the outer layer made of fibre reinforced plastic (glass/epoxy). Main goal of the prototype is to have an idea of the real weight, an inside in the construction and production methode and the possibility to touch/feel the materials. Certain material combinations are therefore replaced by cheaper ones. For testing a bigger panel should be made with the real material combination as described in the panel design.

The weight reduction for the skeleton will be around 25 percent. With a prototype of a wall panel the weight reduction per m2 compared with the construction nowadays is around 35 percent. However functional requirements as sound reduction and fire resistance need to be tested and certified before use. For architectural items main reduction in weight can be found in the flooring, wall and ceiling panels and furniture. Overall 40 percent in weight can be saved.

The overall weight saving will be around 23 percent for both structural and architectural on the total weight. Advantages can be found in assemblage, maintenance, longer life-cycle, flexibility (change of POB), durability, performance, and transport fuel (less CO2).
This graduation script is made for the Material research & Design lab of the TU Delft. In cooperation with the company Hertel research has been done for new (lightweight) materials and improvement in the design for offshore Living Quarters (Hotels in the sea).

At first the situation nowadays and the specific problem has been formulated. Secondly different materials have been investigated by a literature study. Also by the research at reference projects possibilities and difficulties became clear. Out of these conclusions, constraints have been made. Scenarios are described and out of this a design is made by a description of the materials, drawings, calculations and a prototype. At last conclusions and recommendations will be given.

I would like to thank my tutors Ir. F. Veer, Ir. A. Borgart and Ir. G. Hobbelman for their guidance, help and advising during this research. Also the board of examiners delegate S. W. Bijleveld I would like to thank for his presents and critics on my presentations.

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At last I want to thank my Family for their support.

Delft, October 2010

Jefta van der Elst
## INDEX

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Summary</td>
<td>3</td>
</tr>
<tr>
<td>Foreword</td>
<td>7</td>
</tr>
<tr>
<td>Index</td>
<td>9</td>
</tr>
<tr>
<td>Abbreviations</td>
<td>13</td>
</tr>
</tbody>
</table>

### 1. INTRODUCTION
- 1.1 Product development
- 1.2 Offshore industry
- 1.3 Hertel

### 2. DESIGN GOAL
- 2.1 Problem
- 2.2 Weight saving nowadays
  - structural (steel -> alu)
  - insulation
  - screed
  - wall panels
  - doors
  - wet unit
  - furniture
- 2.3 Requirements
- 2.4 Desirable
- 2.5 Main question

### 3. RESEARCH
- 3.1 Steel
  - history
  - joints
  - fire resistance
  - advantages
  - disadvantages
- 3.2 Aluminium
  - history
  - joints
  - fire resistance
  - advantages
  - disadvantages
- 3.3 FRP
  - history
  - joints
  - fire resistance
  - advantages
  - disadvantages
- 3.4 References
  - Spacebox
  - Detos houses
  - Cargoshell
  - SPS sandwich plates
  - ACROSOMA structural
  - Everstrip
  - CoreCork

### 4. PRELIMINARY DESIGN
- 4.1 Design constrains
  - rules DNV
  - acoustic
  - thermal
  - fire resistant
- 4.2 Scenarios
  - low tech
  - medium tech
  - high tech
- 4.3 Design
  - functional
  - structural
  - calculations
- 4.4 Transport
- 4.5 Conclusions
5. CONSTRUCTION RESEARCH

5.1 construction phase
5.2 transport
5.3 lifting
5.4 in place
5.5 panel
  • no panel
  • fixed
  • clamped
5.6 pad eye
5.7 buckling

6. PANEL

6.1 Composition
6.2 Assemblage
  • bolted
  • hanging
  • clamped

7. PERFORMANCES

7.1 Acoustic
7.3 Thermal
7.4 Fire resistance

8. FINAL DESIGN

8.1 Design
8.2 Prototype
8.3 Cost
8.4 weight

9. CONCLUSIONS

9.1 New elements
9.2 Conclusions
9.3 Recommendations

Sources
Annex
**ABBREVIATIONS**

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FRP</td>
<td>Fibre Reinforced Plastic</td>
</tr>
<tr>
<td>G(F)RP</td>
<td>Glass (Fibre) Reinforced Plastic</td>
</tr>
<tr>
<td>LQ</td>
<td>Living Quarter</td>
</tr>
<tr>
<td>OI</td>
<td>Offshore Industry</td>
</tr>
<tr>
<td>POB</td>
<td>Persons on Board</td>
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<tr>
<td>UC</td>
<td>Unity check</td>
</tr>
<tr>
<td>SF</td>
<td>Safety factor</td>
</tr>
<tr>
<td>ASTM</td>
<td>American Society for Testing and Materials</td>
</tr>
<tr>
<td>HSLA</td>
<td>High-Strength Low-Alloy Steels</td>
</tr>
<tr>
<td>BCE</td>
<td>Before the Common Era</td>
</tr>
<tr>
<td>CE</td>
<td>Common Era</td>
</tr>
<tr>
<td>Solas</td>
<td>Safety of Life at Sea</td>
</tr>
<tr>
<td>DNV</td>
<td>Det Norske Veritas</td>
</tr>
<tr>
<td>UV</td>
<td>Ultraviolet</td>
</tr>
<tr>
<td>PEEK</td>
<td>Polyether ether ketone</td>
</tr>
<tr>
<td>Tm</td>
<td>Melting temperature</td>
</tr>
<tr>
<td>PIR</td>
<td>Polyisocyanuraat</td>
</tr>
<tr>
<td>PUR</td>
<td>Polyurethaan</td>
</tr>
<tr>
<td>MIG</td>
<td>Metal Inert Gas</td>
</tr>
<tr>
<td>TIG</td>
<td>Tungsten Inert Gas)</td>
</tr>
<tr>
<td>FS</td>
<td>Friction-stir</td>
</tr>
<tr>
<td>HAZ</td>
<td>Heat affected zone</td>
</tr>
<tr>
<td>CTE</td>
<td>Coefficient for thermal expansion</td>
</tr>
<tr>
<td>WW2</td>
<td>World war 2</td>
</tr>
<tr>
<td>HVAC</td>
<td>Heating Ventilation Air Conditioning</td>
</tr>
</tbody>
</table>
#1: Delft Nuna 4

#2: Investment against quality

#3: Investment for lightweight structures against time

<table>
<thead>
<tr>
<th>Strong</th>
<th>Opportunities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good knowledge infrastructure</td>
<td>Use of new materials in important (export-related) branches</td>
</tr>
<tr>
<td>Strong applications, like automotive, machines, electronics</td>
<td>Saving of raw material by the use of new materials</td>
</tr>
<tr>
<td>Strong relations between industry and science</td>
<td></td>
</tr>
<tr>
<td>High educated personnel</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Weakness</th>
<th>Risks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time to market. Development time is too long in comparison with short production cycles</td>
<td>Weakening of innovation because of movement to the Asia market</td>
</tr>
<tr>
<td>Disappearance of end production to S-O Asia</td>
<td>High costs for energy and raw materials</td>
</tr>
<tr>
<td>Lack of a roadmap, commitment for the long-term strategy</td>
<td>Shortage of skilled educated personnel</td>
</tr>
</tbody>
</table>

#4: Why product development
1. INTRODUCTION

The lack of raw materials and oil, the need for recycling and a cleaner CO2 free energy supply are the most important impulse to search for innovative materials. In the Netherlands there is a strong tradition in materials, like metals, polymers, coatings, ceramics, glass and concrete.

There are about 1700 companies who take part in this research and development (R&D). A lot of these are international researchers and specialists (Akzo Nobel, Corus Tata, Dow, Ten Cate, DSM). The Dutch government contributes 175 million euro for five big, four years lasting, and material-research programs.

• The innovative research program (IOP) self-healing materials
• Material to innovate the Industry (M2I)
• Polymers innovation program (PIP)
• Biomedical Materials (BMM)
• Advanced Dutch energy materials innovation lab (ADEM)

The Dutch Institute for metals Research (M2I) is focusing on innovative materials for the Dutch industry. By the use of lighter materials and more functionality and a longer lifecycle, energy and materials can be saved.

These researches look into social challenges, like the development in lightweight construction materials (to reduce fuel), corrosion resistant materials and for example fireproof textile. Structural materials made of plastics, metal and concrete are important to build roads, bridges, tunnels and banks.

One example of the advanced Dutch material technology is the Delft Nuna 4 (##1) who won the World Solar Challenge. It is a safe, aerodynamic, lightweight car driving on solar cells. Because of the demand for lightweight constructions fiber reinforced plastics (composites) and hybrid material, like plastic in combination with aluminium, become more important.

In a lot of applications there is a strong development in technology like in the car- and airplane industry, medical industry, machines, high-tech industry, packaging, and maritime industry.

In the offshore industry development goes slow. Materials that are of interest for offshore are metals, coatings and composites. There is a good reason for searching new materials for the offshore, for example weight and corrosion is one of their biggest problems.

1.1 PRODUCT DEVELOPMENT

Product development (PD) is the term used to describe the complete process of bringing a new product or service to the market. There are two parallel paths involved in the PD process:

• Product design
• Marketing analysis

A typical product development process needs the following steps:

1. research
2. concept
3. preliminary marketing
4. prototype (testing)
5. definitive marketing
6. production

Product development involves time and investment of money. When focusing on the quality of a product against investment the graph (#2) on the left shows a critical point where appreciation is no longer of interest because costs are to much. The quality of a product is optimal when for minimum costs a maximum quality is achieved. Integrated in the design goal another graph (#3) of investment (kg/euro against years) can be made. Out of these graphs critical point can be noted whereby high costs will not always result in better performance or appreciation. However it is not always clear when this point is reached because of new technical developments.

Out of research it is concluded that about 90% of product development will not get a break trough. This seams to be an high number of failure. Mostly because of lack of money or a development time that is too long in comparison with the market requests (#4).

As with designing any materials (plastic, steel, aluminum, wood, ceramic, etc.) it is important to know their behaviors in order to maximize product performance- to-cost efficiency. Unfortunately there is no one plastic or process (as with other materials such as steel, wood, glass, etc.) that provides all types of performance requirements.

Target is to achieve the basic three general requirements
#5: Oil and gas platform in the North Sea
of design success:
1. economical,
2. functional, and
3. attractive in appearance.

The first step is a general product description with requirements such as what is it to do, how it is to be used, where it is to fit, etc. The next step is to prepare a detailed design with drawings. Once the drawings are available, prototyping and testing can be initiated.

Manufacturing may request a new design to simplify assembly or minimize breakage, or management may demand that costs be reduced. The aim of product design or redesign is to achieve the best possible product at the least practical cost. It is a dynamic procedure, with the key being communication.

Unfortunately for steel and other materials, plastics continue to expand its use where these other materials are not competitive property wise and/or cost-wise.

First, plastics provide enormous freedom of shape. They also permit product production that is faster and more consistent, and they can do it all at a fraction of the cost for making non-plastic products. On a per-pound basis, they are actually more costly than many competitive materials. But the process ability and relatively low density of plastics (which translates into lower costs per volume) gives them a big economic advantage.

1.2 OFFSHORE INDUSTRY

When we look at the (North) sea we enjoy the smooth sound of the waves, the salty air and the wind blowing in our face.

Behind this scene there is a total different world. A world of hard work to fulfill the demands of the world. A sea full of platforms drilling into the ground to make our car run, machines work and even to get your meal ready. (#5)

There are several types of platforms and rigs, some examples:
- fixed platforms (concrete and/or steel)
- compliant towers
- semi-submersible platforms
- jack-up platforms
- floating production systems
- tension-leg platform

On these platforms people are working and need the basic needs to complete there work in a good manner. Normally the workers stay for two weeks. The module is called the Living Quarter (LQ) and contains the cabins, recreation areas, kitchen etc. It can also be called a Sea Hotel.

Attention must be given that the LQ should be the safest area on the island and therefore needs to be built and

‘Making things lighter is not just a matter of choosing lighter materials. Efficiency also involves making materials do what they do the best!’
#6: North sea gas leak 1988

#7: Gulf of Mexico explosion 2010

#8: Hertel projects
approved by very strict rules and parties. In July 1988 for example, 167 people died when Occidental Petroleum’s Piper Alpha offshore production platform, on the Piper field in the UK sector of the North Sea, exploded after a gas leak. (#6) This accident greatly accelerated the practice of providing living accommodations on separate platforms, away from those used for extraction. By technical improvement and experience over the years the rules gets more strict to guarantee the safety.

More recently (April 20, 2010) an explosion on a platform in the Gulf of Mexico killed 11 platform workers and injured 17 others (#7). The blowout caused a major spill of oil which flowed for three months (total spill 780,000 m³).

- 570 Oil/gas platforms on the North sea
- Average 80 people working per platform (45,600 total)
- Future plans for (floating) windmills
- New developments for the Caspian Sea, Brazilian waters and Arctic regions.

1.3 HERTEL

Hertel is one of the biggest companies in the Netherlands that offers integral services for industries. The company exists for over 110 years and started with their main experience in insulation material. Hertel Offshore is one of Hertel’s departments that offer turn-key solutions for accommodation in the offshore sector. They have broad experience in installing and creating furniture and devices into modular housing and technical units. They established a strong reputation in the market for the past decades. The company runs under high quality standards and the insurance of having the right people to solve any problem.

Strengths

Hertel offshore has a broad expertise of working with steel as the main material for their products. Knowledge about steel and technologies for processing it are part of the in-house skills.

Hertel acquired a solid understanding and much experience in furnishing and installing living quarters, in which they have a strong portfolio. Furthermore they can relay in the diverse contacts and suppliers that manage the best qualities and specifications for extreme conditions. This allows Hertel to conceive and ensemble the best design with the specific requirements for each client.

Projects (#8)

- Expandable shelter
- Blast Resistant Modules
- Living Quarter
- Prefab cabins

Goal

Because of the economic crisis and the competition from other upcoming industries in the world (Asia), Hertel offshore needs to search for innovative solutions in their design. By creating new, innovative, ‘smart’ products that can suit the high demands of their clients they can get one of the main players in the world. It should not only be found in the first costs (purchase) for the design but the costs in the long term for the client. Introducing new (better-performing) materials is one of the main research subjects.
#9: The logistics of offshore building

#10: Weight per discipline
2. PROBLEM

In the Offshore Industry (OI) steel is the material to use. For years now the OI is increasing the quantity of platforms to fulfill the demand for oil and gas. Due to the economic crisis money has to be invested carefully. Oil platforms get overloaded with equipment and steel modules to delay the fabrication of a new platform. The normal design life of the platform is calculated for 20 years. When using lightweight modules the design life can be extended. It is even more important for drill rigs or floating units to reduce the weight to save fuel.

2.1 DESIGN GOAL

There is a weight problem. The weight problem already starts in the production phase. Heavy pieces of metal must be moved using cranes. After fabrication the transport is an issue. Not only because of the volume but also the costs that has to be made because of the weight. Ship- or air freight is normally based on volume and weight. When arrived close to the platform the modules must be lifted using a crane. Expensive cranes must be hired or even sometimes the modules must be split what gives additional work in the fabrication progress. It can be noted that reducing the weight results in cost-saving (#9).

When we look at the module itself we can see that several disciplines are involved that causes the total weight:

- Structural (structure and cladding)
- Architectural (internal sandwich wall- and ceiling panels, floor finish, doors etc)
- Piping (black and grey water extract, fresh water supply)
- HVAC (ducts, dampers)
- Loss control (safety equipment, sprinkler)
- Misc. (helideck, walkways)

To make a good comparison three projects are analyzed based on the discipline weight impact on the total weight:

- A 75 men LQ
- A 50 men LQ
- A 18 men LQ

It can be noted that the structural weight ration is 54% of the total weight (#10). On the second place architectural with 19%. For architectural there is a strong development going on for weight saving. Aluminium sandwich constructions for doors and furniture are now often prescribed in the project rules. However there are still ways for improvement (for example insulation type). For helidecks and walkways it is common to use an aluminium structure. For the other disciplines the weight impact can almost be neglected.

2.2 WEIGHT SAVING NOWADAYS

As described before the main contributing disciplines in weight for a LQ are structural and architectural (incl. insulation). Beneath these two disciplines will be evaluated on their possibilities for weight decrease nowadays.

Structural

Shifting to another material for the structure by aluminium should give a weight reduction of about 20%. However, more in detail, focusing on the dimension for plates, beams etc. and the risks by fire the weight reduction is minimal. For production it is the goal to have minimum quantity of moulds to reduce the costs. Aluminium has a wide range of profiles. For the structure this advantage is often not fully taken in account, because time in the design phase is short and aluminium profiles are therefore unfortunately almost the same as in steel.

Architectural Insulation

To optimize weight nowadays, the possibility in use of Firemaster insulation instead of Rockwool is an option. This lightweight insulation can be used either partially or completely on both walls and deck, and can reduce the weight with approximately 35% if used solely. Specific gravity for the insulation investigated is as following:

Specified today:
- A60 Internal area: 30+30 mm Rockwool Marine Wired Mat 125: 8 kg/m2
- A60 External area: 30+40 mm Rockwool Marine Wired Mat 125: 9 kg/m2

Possible alternative:
- A60 Internal and External: 50 mm Fire master (96 kg/m³): 4,8 kg/m2

Regarding sound reduction the use of Firemaster instead of Rockwool as insulation in cavity walls
#11: Use of FRP offshore
is not considered to have negative consequences provided that the distance between plates is unchanged. The sound reduction of porous materials is dependent of the flow resistance, which is a function of the fibre size and material density. A lightweight material may replace a more heavy material if the fibre thickness is smaller. Firemaster with density 96 kg/m3 has similar sound insulation properties as Rockwool.

**Screed**
Screed in both dry and wet areas is a component of main concern when evaluating weight. As a passive fire protection of decks the minimum thickness of screed in areas with low fire loads (like cabins) is 5 mm for Maxit and Acrylicon, and 7 mm for Epoxy screed. In highly exposed rooms (like linen, dry store) the minimum screed thickness must be decided independently and will often be between 10-15 mm. The specific gravity of considered products is as following:

- Acrylicon 2,0 kg/mm/m2
- Epoxy 2,1 kg/mm/m2
- Maxit 1,85 kg/mm/m2
- Boliscreed 1,2 kg/mm/m2

**Wall and ceiling panels**
As shown in the below table weight reduction can be found in using other materials for the composition of the panels. However certification (testing) takes a lot of time and money, and therefore the alternative panels are more costly.

Specified today:
- B15 Lining panel: galvanized steel / core/ galvanized steel: 14 kg/m2
- B15 Partitioning panel: galvanized steel / core/ galvanized steel: 20 kg/m2
- A60 Partitioning panel: galvanized steel / core/ galvanized steel: 32 kg/m2

Possible alternative:
- B15 Lining panel: laminate / core/ laminate: 9 kg/m2
- B15 Partitioning panel: laminate / core/ laminate: 15 kg/m2
- A60 Partitioning panel: glass fibre / core/ glass fibre: 19 kg/m2

**Doors**
For internal doors there are alternatives applicable in an aluminium and FRP variant, however certification is at the most B15 rated. Beside this the products are costly and therefore not often used in the offshore.

**Wet units**
For wet units a good alternative is applicable. Instead of the units build up with conservative materials a GRP wet unit is available on the market. The weight decrease involves approximately 30 percent for a standard unit (#11).

**Furniture**
Poppel and Honeycomb has an approximate 40-45 % weight decrease compared to a core material of MDF. Omitting furniture like gym equipment and office furniture during lifting could reduce the weight and therefore costs. However furniture has to be brought in separately and installed when the module is on his place. This can cost a lot of material handling and therefore man-hours.
2.3 REQUIREMENTS
In consultation with the company Hertel and the wishes of the clients the design must comply with the following requirements:

• The design must comply to the general Offshore rules and regulations (Solas, DNV)
• Must have a significant weight reduction (goal is min. 20% reduction on total weight)
• Modules are (stackable) max. 4 levels
• Must be able to transport and lifted
• Must be A60 rated (fire resistant)
• Total wall construction; acoustic (Rw 45, vibrations), thermal (U value 0,5)
• Safe construction (environmental loads, damage control)
• Interaction with other disciplines (penetrations, supports etc.)

2.4 DESIRABLE
In consultation with the company Hertel and the wishes of the clients the design desirables are:

• Short construction time
• Simple production method
• Total cost-saving
• Use of in-house knowledge
• Use of in-house machines
• Maintenance free
• Replaceable panels
• Environmental
• Recyclable
• Freedom of geometry (every project is unique?)
• Safety

2.5 MAIN QUESTION

'Can the existing Living Quarter be made of another material then of steel to succeed in a lightweight design taking into account the strict offshore rules and technical performances?'
#12: CES material charts

#13: Material properties
3. MATERIAL RESEARCH

Before starting a research for materials applicable in the offshore a study is performed with the help of the program CES. In the program a database with all kind of material, including there properties, is collected and updated. It is possible to apply a range of numerical and graphical selection criteria to identify which materials meet the specific design objective. The most powerful of these are material property charts (sometimes called Ashby charts). Out of this study graphs and tables are made to have an overview of the potential materials that could be used (#12, #13). Three materials will be analysed by literature research. For each material four topics will be described: history, joints, fire resistance and at last a sum-up of the advantages and disadvantages.

3.1 STEEL

History

The production of iron by humans began probably sometime after 2000 BCE in south-west or south-central Asia, perhaps in the Caucasus region. Thus began the Iron Age, when iron replaced bronze in implements and weapons. This shift occurred because iron, when alloyed with a bit of carbon, is harder, more durable, and holds a sharper edge than bronze. For over three thousand years, until replaced by steel after CE 1870, iron formed the material basis of human civilization in Europe, Asia, and Africa.

Ironmakers of the late Middle Ages also learned how to transform cast pig iron into the more useful wrought iron by oxidizing excess carbon out of the pig iron in a charcoal furnace called a finery. After 1784, pig iron was refined in a puddling furnace (developed by the Englishman Henry Cort). The puddling furnace required the stirring of the molten metal, kept separate from the charcoal fire, through an aperture by a highly skilled craftsman called a puddler; this exposed the metal evenly to the heat and combustion gases in the furnace so that the carbon could be oxidized out. As the carbon content decreases, the melting point rises.

The mass-production of cheap steel only became possible after the introduction of the Bessemer process, named after its brilliant inventor, the British metallurgist Sir Henry Bessemer (1813-1898). Bessemer reasoned that carbon in molten pig iron unites readily with oxygen, so a strong blast of air through molten pig iron should convert the pig iron into steel by reducing its carbon content. The Bessemer process did not have the field to itself for long as inventors sought ways around the patents (over 100 of them) held by Henry Bessemer. In the 1860s, a rival appeared on the scene: the open-hearth process, developed primarily by the German engineer Karl Wilhelm Siemens. This process converts iron into steel in a broad, shallow, open-hearth furnace (also called a Siemens gas furnace since it was fueled first by coal gas, later by natural gas) by adding wrought iron or iron oxide to molten pig iron until the carbon content is reduced by dilution and oxidation.

The mass production of cheap steel, made possible by the discoveries over the years, has revolutionized our world. Some products made possible (or better or more affordable) by cheap, abundant steel: railroads, oil and gas pipelines, refineries, power plants, power lines, assembly lines, skyscrapers, elevators, subways, bridges, reinforced concrete, automobiles, trucks, buses, trolleys, refrigerators etc.

Steels for structural uses may be classified by chemical composition, tensile properties, and method of manufacture as carbon steels, high-strength low-alloy (HSLA) steels, heat-treated carbon steels, and heat-treated constructional alloy steels.

Carbon Steels

A steel may be classified as a carbon steel if:
1. the maximum content specified for alloying elements does not exceed the following: manganese-1.65%, silicon-0.60%, copper-0.60%;
2. the specified minimum for copper does not exceed 0.40%; and
3. no minimum content is specified for other elements added to obtain a desired alloying effect.

- High-Strength Low-Alloy Steels (HSLA)

Those steels which have specified minimum yield points greater than 40 ksi and achieve that strength in the hot-rolled condition, rather than by heat treatment, are known as HSLA steels. Because these steels offer increased strength at moderate increases in price over carbon steels, they are economical for a variety of applications. A242 steel is a weathering steel, used where resistance to atmospheric corrosion is of primary importance.

A588 and A242 steels are called weathering steels because, when subjected to alternate wetting and drying in
most bold atmospheric exposures, they develop a tight oxide layer that substantially inhibits further corrosion. They are often used bare (unpainted) where the oxide finish that develops is desired for aesthetic reasons or for economy in maintenance.

- **Heat-Treated Carbon and HSLA Steels**
  Both carbon and HSLA steels can be heat treated to provide yield points in the range of 50 to 75 ksi. This provides an intermediate strength level between the as-rolled HSLA steels and the heat-treated constructional alloy steels.

- **Heat-Treated Constructional Alloy Steels**
  Steels that contain alloying elements in excess of the limits for carbon steel and are heat treated to obtain a combination of high strength and toughness are termed constructional alloy steels. Having yield strength of 100 ksi, these are the strongest steels in general structural use. Constructional alloy steels are also frequently selected because of their ability to resist abrasion. For many types of abrasion, this resistance is related to hardness or tensile strength. Therefore, constructional alloy steels may have nearly twice the resistance to abrasion provided by carbon steel. Also available are numerous grades that have been heat treated to increase the hardness even more. There is also a Grade 50S, where the S indicates the steel must be killed (during the melting process steel will be treated by keeping the NO2 level low to maintain a good quality).

- **ASTM A606**
  Covers high-strength low-alloy hot- and cold-rolled steel sheet and strip with enhanced corrosion resistance. This material, available in cut lengths or coils, is intended for structural and other uses where savings in weight and improved durability are important. It may be ordered as Type 2 or Type 4, with atmospheric corrosion resistance approximately two or four times, respectively, that of plain carbon steel.

**Joints**
- **Bolts**
  Most field connections are made by bolting, either with high-strength bolts (ASTM A325 or A490) or with ordinary machine bolts (A307 bolts), depending on strength requirements.
- **Welding**
  A proven, reliable method widely used for several constructions

**Fire resistance**
There are two basic ways to provide fire resistance: first, to design the structure using the ordinary temperature properties of the material and then to insulate the members so that the temperature of the structure remains sufficiently low, or secondly, to take into account the high-temperature properties of the material, in which case no insulation may be necessary.

The degree of fire resistance required of a structural member is governed by the building function (office, shop, factory, etc.), by the building height, by the compartment size in which the member is located, and by whether or not sprinklers are installed.

Steel begins to lose strength at about 200°C and continues to lose strength at an increasing rate up to a temperature of about 750°C, when the rate of strength loss flattens off.

There are two methods of assessing the fire resistance of bare steel members. The first, the load ratio method, consists of comparing the design temperature, which is defined as the temperature reached by an unprotected member in the required fire-resistance time, with the limiting temperature, which is the temperature at which it will fail. The load ratio is defined as: If the limiting temperature exceeds the design temperature no protection is necessary. The method permits designers to make use of reduced loads and higher strength steels to achieve improved fire-resistance times in unprotected sections. The second method, which is applicable to beams only, gives benefits when members are partially exposed and when the temperature distribution is known. It consists of comparing the calculated moment capacity at the required fire-resistance time with the applied moment. When the moment capacity exceeds the applied moment no protection is necessary.

**Advantages**
- The material properties are more consistent, and therefore production with these materials is more reliable.
- Longer life cycle
- Weldability, bolting as proven connection method
- Ductility, It allows redistribution of stresses in continuous members and at points of high local stresses
- Availability, costs
- Recyclable, one of the most recycled materials in the world. In 2008, more than 83% in US was recycled
- Choice, High strength low alloy steel (HSLA), cold rolled steel.
- Less material is needed, because it is lighter and
#14: Statue of Eros, 1893

#15: Aluminium bridge Sunderland UK

#16: Aluminium helideck
stronger.
• Lower material cost, because of the higher strength less steel is necessary.
• Resistance is better. Durability and life cycle is increased because of the high strength.

Disadvantages
• Weight
• New kinds of steel requires new knowledge
• Rust, steel needs to be sandblasted and painted hereafter.

3.2 ALUMINIUM

History
The breakthrough of aluminium came in 1886 when two young men, aged 22, independently invented the same electrolytic process for smelting aluminium. In the years following 1886, the newly available metal was tried for a wide range of uses, some successful, some less so. A famous example from that time is the statue of Eros in Piccadilly Circus, London, cast in 1893 (†14). Another is the sheet metal roofing of the dome of the church of San Gioacchino in Rome in 1897. Both of these are still in good condition.

Aluminium was used for panelling on railway coaches, and Russia placed an order for aluminium goods-wagons. There is a report of a demountable boat to be carried into the interior of Africa by European explorers (actually by their porters). And another of a prefabricated portable aluminium house invented by Mr Howes of Seattle, USA, weighing 70kg, for use by gold-diggers in the Klondyke (1897). Unfortunately we know little as to how those early efforts fared, except that Yarrow’s torpedo-boat was a failure, because it was in an unsuitable 6% Cu alloy which corroded.

In order for aluminium to be useful as a structural metal, it was essential to develop suitable alloys, since the pure metal was rather weak. The pioneer of alloy development was the German metallurgist Alfred Wilm, who discovered age hardening.

The application which put aluminium on the map as a structural metal was its use in aircraft, first in airships and later in aeroplanes. Aluminium’s huge step forward was its use for military aircraft in World War 2.

New technology since 1945
• Alloy usage
• Large rivets
• Welding arc-welding technique was unsatisfactory for aluminium because the necessary fluxes were highly corrosive. The solution lay in processes using an inert gas (argon or helium) to shield the arc. The first to appear was TIG. Recently (in the early 1990s), we have seen the invention, by the TWI (formerly The Welding Institute) in Britain, of the promising new friction-stir process that now is being used
• Extruded sections
• Adhesive bonding in some applications this is a preferred alternative to welding and its use is likely to grow
• Milling
• This development is mostly of interest for aircraft

A bascule bridge in such material at the docks in Sunderland, UK, failed within a few years, due to corrosion in the severely polluted marine/industrial atmosphere (†15). These failed by fatigue after a very short life. It was soon realised that the best alloy for civil engineering structures is usually the stronger type of 6xxx-series material, although the weldable kind of 7xxx is sometimes preferred. A notable example of 7xxx usage is in military bridges.

A more recent heavy structural development is in the offshore field. Here aluminium is gaining acceptance as a valid material for modules on fixed platforms, where the cost of installation critically depends on weight. Typical examples are helidecks and accommodation modules (†16). The latter may be described as all-aluminium five-storey hotels that are floated out and lifted into place in one piece, complete with cinema.

Joints
• Mechanical joints
• Bolting and screwing
The main decision in the design of a bolted joint is the choice of bolt material, for which there are three basic possibilities: aluminium bolts, austenitic stainless steel bolts, steel bolts (suitably protected).
#17: Weld failures; weld metal, fusion boundary, HAZ

#18: Friction-stir welding
• Friction-grip bolting
The technique is less advantageous than in steel. High-strength friction-grip (HSFG) bolts, made of high tensile steel, are employed for joints loaded in shear when joint stiffness at working load is the prime requirement.
• Riveting
In light-gauge construction, the decision whether to rivet or weld is slanted less towards welding than it is in steel. Aluminium rivets should not be used in situations where they have to carry tensile loading.
• Welded joints
There are two essential differences from steel: firstly, the weld metal is often much weaker than the parent metal; and, secondly, failure may occur in the heat-affected zone (HAZ) rather than in the weld itself. The weld metal can be stronger or weaker than the HAZ material, depending on the parent/filler combination. It tends to be less ductile and better joint ductility is obtained when failure occurs in the HAZ (#17).
• Use of arc welding
Over the last 25 years, arc welding has achieved complete acceptance as a method for joining aluminium, following the American development of gas-shielded welding in the 1950s. These replaced ordinary stick welding, which had proved useless for aluminium. Two gas-shielded processes are available: MIG (Metal Inert Gas) and TIG (Tungsten Inert Gas). MIG is a direct current (DC) process with electrode positive. It is similar to CO2 welding of steel. TIG is an alternating current (AC) process. The water-cooled torch has a non-consumable tungsten electrode, and as with MIG it delivers a flow of argon. The filler wire is held in the other hand and fed in separately. TIG requires more skill than MIG, both to control the arc length and to feed in the filler. Specification of the electrode/filler wire for MIG or TIG is a design decision and should not be left to the fabricator. The selection depends on which of the following factors is the most important: weld metal strength; corrosion resistance; or crack prevention.
• Friction-stir (FS) welding (#18)
FS welding provides a simple means of making butt-joints, for which it has the following advantages over MIG and TIG. An FS joint, with its flat surfaces, has a tidier geometry than an arc-welded joint. From data so far available, it appears that FS joints are stronger than arc-welded ones. Clearly FS joints are superior in fatigue, because of their good profile. Once the welding parameters have been established, an FS weld is less operator dependent. The FS process is suitable for welding all the main alloy types. The chief disadvantage of the FS process is the need to provide a rigid support system, to react against the considerable downward force exerted by the welding tool. Another snag is that a hole remains at the end of each weld run, formed when the tool is withdrawn. This has to be filled in somehow, an available method being friction taper plug welding. As with arc welds, run-on and run-off plates are generally necessary, unless it is possible to cut off the end material. Such a product is attractive in truck bodies, ships, offshore modules and bridges.
• Bonded joints
The method is acceptable for use with all the alloy groups, and has the following advantages when compared with other connection methods:
1. absence of any weakening in the connected parts;
2. good appearance;
3. good fatigue performance;
4. good joint stiffness;
5. no distortion.

Unfortunately, there are some drawbacks in the use of bonding which tend to limit its range of application:
1. most adhesives lose strength at quite a modest temperature.
2. some will deteriorate when immersed in water (for a month or more).
3. adhesives undergo creep under long-term sustained loading, if the stress level is too high.
4. there is a risk of cracking under impact conditions with some of them.
5. All of these tendencies can be minimized by correct choice of adhesive.

In choosing the most suitable adhesive for a given application the following are possible factors to consider:
• Curing time/pot-life
• Toughening
• Slumping (loss of adhesive)
• Operating temperature, Many of the adhesives used on aluminium begin to lose
• strength at temperatures over 40° C. Some, however, are designed to operate up to 160° C
• Performance in a wet environment
• Ductility
#19: Conventional profiles

#20: Extruded aluminium profiles
But its successful use is critically dependent on good practice by the fabricator, especially as regards preparation of the surfaces. Adhesives used with aluminium are usually epoxy materials, two main types being available: the two-component and the one-component.

**Fire resistance**

In 1981 three of the British warships made of aluminium superstructures sunk in the Falklands war. At the time, the press stated that in the severe fires preceding these sinkings the aluminium had actually burnt. This was completely untrue. The aluminium structures lost strength and distorted, but did not burn. Aluminium sections, plate, sheet, foil and wire will not support combustion. Only in the form of very finely divided powder or flake can the metal be made to burn, as can finely divided steel. The melting point is 660°C for pure aluminium compared with 1500°C for mild steel, while the values for the alloys are somewhat lower. The boiling point is 1800°C. For this reason aluminium as a structural material should be insulated from both sides to prevent melting. Mostly insulation that is visible from the outside needs cladding in front.

**Advantages**

- **Lightness**, aluminium is light. Weight pure aluminium \( \rho = 2.70 \text{g/cm}^3 \) Structural steel \( \rho = 7.9 \text{g/cm}^3 \)
- **Non-rusting.** Aluminium does not rust and can normally be used unpainted. However, the strongest alloys will corrode in some hostile environments and may need protection.
- **Extrusion process.** This technique, the standard way of producing aluminium sections, is vastly more versatile than the rolling procedures in steel. It is a major feature in aluminium design (#19, #20).
- **Weldability.** Most of the alloys can be arc welded as readily as steel, using gas shielded processes. Welding speeds are faster.
- **Machinability.** Milling can be an economic fabrication technique for aluminium, because of the high metal removal rates that are possible.
- **Glueing.** The use of adhesive bonding is well established as a valid method for making structural joints in aluminium.
- **Low-temperature performance.** Aluminium is eminently suitable for cryogenic applications, because it is not prone to brittle fracture at low temperature in the way that steel is. Its mechanical properties steadily improve as the temperature goes down.

**Disadvantages**

- **Cost.** The metal cost for aluminium (sections, sheet, and plate) is typically about 1.5 times that for structural steel volume for volume. However an aluminium design can even be cheaper than a steel one because of easier handling, use of clever extrusions, easier cutting or machining, no painting, simpler erection.
- **Buckling**
- Because of the lower modulus, the failure load for an aluminium component due to buckling is lower than for a steel one of the same slenderness.
- **Effect of temperature.** Aluminium weakens more quickly than steel with increasing temperature. Some alloys begin to lose strength when operating above 100°C.
- **HAZ softening at welds.** There tends to be a serious local drop in strength in the heat affected zone (HAZ) at welded joints in some alloys.
- **Fatigue.** Aluminium components are more prone to failure by fatigue than are steel ones.
- **Thermal expansion.** Aluminium expands and contracts with temperature twice as much as steel. However, because of the lower modulus, temperature stresses in a restrained member are only two-thirds those in steel. (Thermal expansion Pure aluminium \( a = 23.5 \times 10^{-6}/\text{°C} \). Structural steel \( a = 12 \times 10^{-6}/\text{°C} \))
- **Electrolytic corrosion.** Serious corrosion of the aluminium may occur at joints with other metals, unless correct precautions are taken. This can apply even when using alloys that are otherwise highly durable.
- **Deflection.** Because of the lower modulus, elastic deflection becomes more of a factor than it is in steel. This is often a consideration in beam design.
3.3 FRP

History

Mankind has used composites already for a long time. Walls were made of straw and mud by the Egyptians, Chinese and Israelis. The function of straw was; water drainage to dry the core, and strength to bind the materials together to prevent cracks. In the grave of Toetanchamon (1350 before Chr) composite arches where found made of glued sinews of animals together with wooden layers. Similar structures have been found in the Old China and Japan where iron and steel where forged together.

'Composite is 'invented' by accident in the US. It happened when someone by accident dropped some bakelite resin (mixture of phenol and formaldehyde) on his clothes. After work he wanted to remove it but it became very hard and impossible to remove. Since then more and more experiments have been conducted. (event around 1908)'

The real beginning of fiber reinforced plastics began in 1868, when John Wesley Hyatt in the USA developed celluloid. However in 1907 Leo H. Beakeland, a Belgian inventor, asks for patent in the USA for a process where phenol and formaldehyde is controlled so that when a fiber material is added and after hardening a suitable insulation material is created. Later on, in 1922, the brand name bakelite has been used.

In 1913 Daniel J. O’Conner asks patent for the so called formica. The process exists of winding of paper, that before winding is soaked in the resin, and after pressing and hardening produces flat plates.

Real development took place in 1940. During WW2 there was a request for ‘radar domes’ made of glass fiber reinforced polyester for the military airplanes. These domes should be resistant for aerodynamic forces and extreme weather but radar signals should be going through. Because of the difficult shape FRP was the most capable material to use. In 1944 the first plane (BT-15) with a fiber reinforced body was flying. After WW2 the material found his way in the society. Applications where growing; boats, cars, busses, pipeline, windmills, hockey sticks, tennis rackets etc. In the same time the materials for the composites where growing like, carbon and aramide fibers.

In the sixties the development of glass fibre reinforced panels is introduced. These panels have a secondary structural function for high rise buildings to distribute the wind loads to the load bearing construction behind. In the Netherlands Jan Brouwer is one of the first who used this in his work. However because of the crisis in 1973 and the poor fire resistance of the elements only few buildings where developed.

In the second half of the seventies introduced glass fibre cement panels. Just a few companies produced some of these insulated sandwich panels. But very soon problems with coatings and water resistance caused lack of interest.

Joints

Joints are necessary in large FRP structures because of production and design considerations. When components are too large to be fabricated in one piece, several parts have to be joined and stiffeners are necessary. Joints are potential failure sites, whether they are adhesively bonded or mechanically fastened, and whether they join two FRP sections, or one FRP component and one constructed from another material. In the construction industry, joint failure in FRPs is likely to mean leakage of water into the building, rather than structural collapse. It is thus recommended that joints should be located well away from supplies of water. On roofs, they should be on ridges and not in gutters. Adequate seal pressure is necessary. Joints should be readily accessible for inspection and replacement.

- Adhesively bonded joints

Adhesive joints in FRP structures are capable of achieving higher strength than mechanical ones and may be preferred for that reason. Their durability depends more on the flexibility and toughness of the resin used in the adhesive than on its strength. Joint strength can be predicted by performing a stress–strain analysis and applying an appropriate failure criterion. Stresses in the adhesive bonds can be predicted using finite element analysis and closed form or continuum mechanics.

- Mechanically fastened joints

Mechanically fastened joints have the advantage that they can be disconnected if desired. These joints fail in the same way as metals, that is in tensile, shear or bending modes, but with the difference that the failure load is not so obvious with FRPs. Bolts offer the greatest mechanical strength obtainable without adhesives, especially when the bolt is a good fit to the hole. Metal bolts must be protected against corrosion, and the use of special materials such as stainless steel can be cost
“You can weld everything to a steel cladding and it gives a reliable connection. It is possible to glue something to a composite structure - very strong even-but on a dirty building site it is not so easy. It is hard for everyone to give worthy values to this matter.”

effective. The edges of drilled holes need to be coated if the joint is exposed to liquids that attack the fibres.

• Repair of FRP structures
  Fibre reinforced polymers require little maintenance. Panels facing prevailing winds are generally ‘self-cleaning’ whilst those in the shadow become contaminated and require periodic cleaning with a mild detergent solution. Mechanical damage, during erection or in service, can be patched and an attempt made to match the original, but site conditions are not usually favourable for proper curing of the resin and a patch is likely to show after a period of weathering. The quality of the repair will also be influenced by the level of surface preparation, the correct use of repair products and the final finishing of the repair. Many of these aspects depend on the skill of the individual conducting the repair. It is better to replace a complete panel or member if this is practicable. Restoration of degraded surfaces can be difficult. In the extreme case of the glass fibres becoming badly exposed, they must be scrubbed off completely before any new surface treatment is applied. As with the repainting of all exterior construction substrates, when coating FRP attention should be paid to surface preparation, the specific paints manufacturers’ instructions and the supervision of trained labour. Surface preparation, prevailing weather conditions during application and the skill of the painter will all have an influence on the service life of the coating, regardless of paint type.

Fire resistance
In the early years of FRPs, their use in public applications such as buildings and transport engendered much enthusiasm among designers and engineers keen to utilise the unique mechanical and optical properties of these exciting new materials, but their fire performance was strangely neglected. After several disasters it became clear that fire performance was as much an essential design criterion as was modulus, yield stress or clarity. Strictly speaking, the resins themselves do not burn; rather it is the highly volatile products of degradation that diffuse out from the polymer and burn in the gas phase immediately above the polymer surface. The heat generated promotes further degradation of the polymer, and the cycle continues.

If strong heating leads to the evolution of flammable volatiles, therefore, there will be implications for the acceptability of the material as a fire risk. Evolution of black smoke or highly flammable gases is extremely undesirable. Smoke density in plastics fires is said to be more important than the toxicity of the fumes in causing fatalities. The complex chemistry occurring in the combustion zone and in the solid polymer during a fire is far from fully understood. It is clear, however, that although in the early stages of a fire there is a plentiful supply of oxygen, ambient oxygen levels can quickly fall. This, coupled with the limited diffusion of oxygen into the polymer matrix, means that the subsequent degradation is predominantly thermal rather than thermo-oxidative. In the oxygen-depleted environment of a fire, combustion is often incomplete, and large quantities of carbon monoxide are produced. Carbon monoxide is held responsible for most fire deaths and smoke is considered the other major factor in preventing escape. Toxic gases such as hydrogen cyanide are invariably produced upon the thermal decomposition of nitrogen-containing polymers such as nylons and polyurethanes; they are also evolved from burning natural products. Resins heated above Tg or Tm (melting temperature) will rapidly lose dimensional and mechanical integrity. The poor thermal conductivity of most resins and consequently of most FRPs means that under high radiant heat, high surface temperatures are soon reached and degradation becomes rapid. Most organic resins will rapidly degrade with the evolution of volatiles at temperatures typically between 300 and 400 °C. These compounds, typically hydrocarbons or oxyhydrocarbons, burn readily in air. Attempts to reduce or eliminate the tendency to burn can involve careful choice of resin and of the nature and physical form of the reinforcement, but the main emphasis is usually on adding special additives to the resin composition. Fire-retardant resin systems can perform well in terms of fire and smoke resistance, although low flammability does not necessarily imply low smoke production. Unfortunately there can be adverse effects on processing, mechanical properties or chemical resistance and this must be carefully considered at the design stage. Intrinsically non-flammable polymers are few, but phenolic resins...
#21: Local compression flang buckling

#22: Lateral-torsional buckling

#23: Reinforcement by FRP strips
have a good reputation in both fire and smoke performance, which has resulted in their becoming increasingly favoured for FRP structures where such concerns are greatest, for example in underground transport. Polyether ether ketone (PEEK) is also a low fire and smoke polymer. Unsatuated polyester, vinyl esters and epoxy resins burn readily, but modified versions are available with improved behaviour. The nature of the reinforcement is important: threedimensional reinforcement may prevent delamination and the exposure of fresh resin-rich layers, and woven roving is less likely to allow structural collapse than chopped strand mat. Fibre bundles have been reported to act as wicks, bringing fresh resin into the combustion zone, although they can also have the reverse effect. Carbon fibres can conduct heat away from the combustion zone, limiting the decomposition of the polymer. Short of building a full-scale structure and setting light to it, it can be difficult to define a material’s fire performance. In practice we rely on small-scale tests. There are many small-scale tests, often specific to one application. Cone calorimetry is rapidly becoming one of the standard tools of fire testing.

**Advantages**

**Structural**
- Tensile strength, range from mild reinforcing steel to stronger than that of prestressing steel. Since FRP composites are materials composed of structural fibers in a plastic matrix, the fibers can be custom-oriented to suit individual needs (Neale and Labossiere 1991).
- Fatigue, Carbon fiber composites exhibit the highest fatigue resistance, followed by aramid and then glass (Neale and Labossiere 1991).
- Low mass, FRP density: 1200 to 2600 kg/m³. Aluminium: 2700 kg/m³, steel density around 7850 kg/m³
- Specific strength, high strength, low density: assembly and disassembly is much easier and less time consuming, lower transportation cost, less lifting equipment costs. (expandable containers)
- Vibration damping, low vibration, use of composites in floors and bearing panels where damping of vibration is of concern can reduce these problems.
- Corrosion resistance
- CTE (coefficient for thermal expansion) value (arctic modules)

**Production**
- Fabrication (panels of core structures between FRP skins)
- Custom geometry

**Disadvantages**
- Color and coating can be integrated. Also non slip properties. Need for and cost of painting is less

**Economic**
- Life cycle costs, less maintenance
- Construction and transportation costs. Less weight, less shipping costs. Less need for heavy construction handling, reduce field assembly costs. Faster construction time.

**Environmental**
- Reduced environmental toxicity, FRP is inert and will not leach into the environment.
- Recycling, marine piles

**Material properties**
- Immune to magnetic forces
- FRP are electrically non-conductive (cable trays)
- Good insulation properties

**Applications**
- Nonstructural applications
- Secondary structural applications (handrails, gratings, ladders)
- Critical structural applications (only when approved)
3.4 REFERENCE PROJECTS

After the material research FRP will be studied in detail by reference projects. At first reference projects will be described, secondly reference component projects. The references chosen are smallscale (housing/handling) projects and components that could be used or at least have the potential to be used in the offshore. Out of this research pros and cons will be found that will be taken into account during the design.

Spacebox

The first time composite is used for dwelling is for student-housing in Delft. The technical university needed more housing for (foreign) students. Composite so far was mostly used in aerospace and ships. The so-called spacebox was a revolutionary development. Composite has some properties that can be used in dwelling also, like strength, lightweight and form-freedom.

The spacebox is a studio of 17m². It is easy to (re)place, a fast construction method and lightweight. (#24) The lifetime is 20 years, they are energy sufficient and environment friendly. The spacebox exists of five prefab elements:

1. housing-unit
2. platform elements
3. connection profiles
4. stairs
5. connections for water, electricity etc.

The R-value is 3.5 W/k². Sound properties are good. The outside surface is smooth, weather resistance and maintenance free. The total construction (104mm) is made of (from inside to outside):

• Spac. Internal finish
• 12mm fire-resistance plate
• 4mm Meranti
• 4mm polyester glass fiber
• 80mm PIR-foam
• 4mm polyester glass fiber

Inside the walls H-shape steel columns are placed for connecting the modules. These are so strong that bordessen and stairs are also connected to these profiles. The total load is transmitted through the steel construction not through the sandwich elements. The load is distributed per unit, to four points going down to the foundation frames. The fire resistance was the biggest challenge. To meet the regulation of the Dutch Bouwbesluit they finally reached a fire resistance of 30minutes. The sandwich panels in combination with the steel construction take care of collapsing in case of fire. The units can also be delivered in the desired colour. The spacebox is still in development. The challenge is a bigger dimension, around 9 x 3.5 meter. Than the floor space has much more flexibility and possibilities.

The total (empty) weight per unit is 2500kg. Dimensions of net floor area of 17m², gross 19m². Volume is 42m³. Each unit costs 20,000 euro.

Architect: Bureau de Vijf.
Construction: Holland Composites Industrials b.v.
Year: 2004

Detos

The modular Detos construction concept is based on standardised glass fibre reinforced polyester sandwich panels (#25). The sandwich is constructed around a PUR foam core of 20 or 50 mm. The concept is from Poly Products BV, a professional specialist in the area of fibre reinforced polyester uses since 1969. The exterior has a smooth finish and is equipped with a UV stabilised, weather resistant gel coat. The interior is finished in a light grey glass fibre structure. The heat insulation Rₐ for the wall construction amounts to 0.98 m² K/W. The sound insulation is standard –/- 15 dB(A).

Properties of the DETOS® building concept:
• Dimensions can be divided flexibly
• Chemical resistant
• Corrosion free
• Demountable
• Sound insulating
• Long life expectancy
• Lightweight
• Low maintenance
• RAL colours of your choice
• Quick installation
• Thermally insulated
• Fixed form and impact resistant Weather resistant
#26: Cargoshell
**Cargoshell**

Cargoshell provides, maintaining the successful qualities of the current container, a number of crucial innovations. Of higher interest is the substantial CO2-reduction that can be achieved by replacing the current containers by Cargoshell worldwide. Cargoshell is manufactured from composites (fibre reinforced plastics), therefore the container is much lighter than the current steel container. Another important innovation is the fact that Cargoshell has a folding mechanism. Steel containers obtain the same amount of space when they are fully loaded as when they are empty. The volume of a folded Cargoshell is ¼ of the original steel container. Momentarily a certified Cargoshell is being developed. Savings in weight and space reduce the operational costs, thus making the Cargoshell an attractive economic concept: Cargoshell is manufactured from composites and therefore much lighter than a steel container. Transportation of a light-weight container saves energy (generated by fossil fuels) and therefore reduces CO2-emission considerably (§26).

The volume of steel containers remains the same whether it is fully loaded or completely empty. Because Cargoshell can be folded after they are unloaded their volume reduces a lot when they are empty. Several empty Cargoshells can be transported together in just one transport. This innovation reduces the use of fuels and therefore the emission of CO2 will reduce as well. An additional advantage is the massive reduction of transport of empty containers. If all steel containers will be replaced by Cargoshells, the amount of transport kilometres will decrease by 75%. In the area of the Port of Rotterdam alone, this will result in reduction of 10,000 transportsations on a yearly base. This means 250 trucks less on the road during rush hours every day. Because the weight of a Cargoshell is much lighter, less energy is needed when transported by crane. Extra energy saving (CO2-emission) can be realized by transporting multiple folded Cargoshells in 1 single movement. The composite Cargoshell also has its advantages concerning temperature-controlled transport. Composites are good insulators.

Especially for temperature-controlled transport a better isolated container can be developed.

An important reason to replace steel containers with Cargoshells which are made out of composites, is the environmental profit (CO2-reduction). The new concept offers possibilities for reducing business-economical costs as well. The following cost reductions can be distinguished:

- Less Maintainance & Repair costs
- Less costs for storage of empty containers in the empty container depot.
- Less movements of empty containers, because several empty containers can be delivered at the same time.
- Less contamination of products, thanks to the smooth interior
- Less shipping costs due to reduction of slots on board of vessels with empty return transport.
- Less need for extra facilities required for product ventilation, which are necessary in traditional containers.
#27: SPS

#28: Acrosoma
**Sps sandwich plates**

Sps sandwich plates

SPS is a structural composite comprising two metal plates bonded with a polyurethane elastomer core. SPS is much simpler and more robust than stiffened steel plate and much lighter and faster to erect than reinforced concrete. SPS is used in a wide variety of applications including structural flooring, stadia and arena terraces, ship repair, shipbuilding and bridges.

In maritime structures, such as the hulls and bulkheads of ships, load-bearing plates are usually made from steel, which is heavily stiffened to prevent buckling. SPS eliminates the stiffening elements, making these structures much less complicated and much less prone to fatigue and corrosion.

In civil engineering structures, such as the decks of bridges and floors in buildings, load-bearing plates are usually made from reinforced concrete. This is because it is difficult to control fatigue and vibration using steel and, with the exception of long-span bridges, the weight penalty of using concrete is tolerated. SPS controls fatigue and vibration and is much lighter than concrete. In addition, SPS plates are prefabricated to a high degree of dimensional accuracy. Using SPS plates reduces ‘wet-work’ on site and de-risks and accelerates the build programme.

SPS can also be used to reinstate or strengthen existing plate structures, such as the cargo holds of ships and the decks of bridges, in a process called SPS Overlay.

Properties of SPS give rise to a number of other valuable benefits:

- Simpler, faster fabrication
- Elimination of stiffeners simplifies structures
- Prefabrication and ease of erection shortens and de-risks construction schedules
- Improved designs and in-service performance
- Less susceptible to fatigue and corrosion, local buckling
- Reduces weight and thickness and allows increased spans
- Reduces build cost
- Reduces construction schedule and risk
- Reduces maintenance cost
- Increases service life
- Increases cargo capacity
- Greater resistance to accidental or extreme impact loads
- Built-in structural fire protection
- Increases rentable floor area
- Built-in blast and ballistics protection
- Built-in acoustic insulation
- Fully recyclable and reusable gives reduced carbon footprint
- Reduced weight results in less materials, less waste and fewer truck loads

**Acrosoma structural panel**

Acrosoma structural panels are tri-dimensional stitched panels. Standard sandwich panels have the problem of delamination between the skin and core, stitched panels avoid this. The standard panel is available in any possible length, 2.78m width an 30mm thickness. This length is possible because of a continuous production process. A foam core is pulled through the entire machine. First, this foam core is covered on both sides on top and bottom by fibres (mostly glass) and stitched. A wetter injects resin and the combination is heated up in a die. Acrosoma stitched panels give the following benefits:

- Lots of combinations are possible for the core, skin, fibres and resin.
- High buckling and impact resistance
- Excellent isolation
- High strength
- Delamination between core and skin are made impossible
- Constant quality
- Practically corrosion proof
- Completely waterproof

Core business for Acrosoma is building of composite (food) containers. The lightweight composite container has been glued to a standard steel container frame. The frame is made of steel IPN 180 profiles with reinforcement at the crucial points. The loading bin itself is made of Acrosoma panels with composite profiles glues together. In case of rough handling the corners are protected with rubber.
**Everstrip**

The ‘Everstrip’ concept is a sandwich floor plate existing of foam with on both sides a reinforced glass fibre. The benefits are:

- lightweight
- high strength
- large expansions possible
- high thermal value
- corrosion resistant

Profiles of a section of 500mm are possible. Besides there is a great range in profiles possible due to the production process. Specific (click) for connecting or penetrations can be integrated. Different foams can be used for specific needs like sound- or fire resistance (#29).

Everstrip standard product has a width of 47mm with a thickness of 22, 27 or 32, but can also be produced in every width and thickness as per client wishes. Everstrip profiles are used to small boats. On a wooden frame the profiles will be fixed and in-between glued together. When the construction is closed lamination can start. This will be done by vacuum injection technique. After hardening the product is smooth and ready for use.

**Corecork**

Cork is the bark of the cork oak tree, is nature’s foam, a foam with a unique combination of properties. Cork cells are small, irregular pentagonal or hexagonal prisms. Fifty per cent of cork is an air like gas enclosed in the cork cells. Other advantages are:

- the high compressibility,
- low weight
- acoustic and thermal insulation
- efficient and clean production, cork is harvested without harming the trees
- sustainable material
- a positive contribution to CO2 fixation during the entire live of the tree (180 years)
- good fire resistance.
- available in blocks, sheets, rolls and strips
- can be trimmed and machined with regular tools
- lower resin absorption and fast curing times
- waste is recyclable
- low water absorption
- anti vibration properties

Some applications where corecork is used already are kayaks, seatings and sandwich panels (#30).
#31: Plan Living quarter nowadays

#32: The concept: Smart Modules
4. PRELIMINARY DESIGN

In this stage a preliminary design will be proposed. Before starting, constrains have to be clear on several topics: functional, structural, acoustic, thermal and fire resistance. Hereafter scenarios will be introduced with their pros and cons. A (preliminary) design will be made for the scenario that is chosen. At last conclusions and recommendations will be formulated.

4.1 DESIGN CONSTRAINTS

**Functional**

The LQ should be the safest area on the platform. In the LQ several functions are needed like; cabins, recreation area, galley, traffic routes etc. It’s like a hotel, perhaps less luxurious. For the square meters, height, material use rules and regulations have been written. Like ‘Bouwbesluit’ for Dutch building design, offshore uses Norsok as the building regulation for architectural design. For example within these rules it will not be allowed to have more then one men sleeping in a bedroom with a min sqm of 8, height 2,4 m. The plan on the left (#31) shows a typical accommodation module design nowadays. A corridor going straight through the building divides the module in two halves where all the functions are situated. The plan is very functional and ‘fit for purpose’. Attention should be given for all the technical systems going through the building, like HVAC ducts, piping and cable trays. At last the safety should be guaranteed by fire divisions and escape routes.

With all the figures and references in mind a ‘smart module’ is introduced. Basically an existing LQ is equally divided (chopped) in several parts. In this module all functions can take place, a bedroom but also a stairway with elevator or in combination large recreation rooms. In this way it is possible to give the client the option to vary in persons on board. There is an opportunity to disconnect some modules and transport it to another platform where people are needed. Nowadays every platform is different and therefore each space applicable for the LQ differs. Each time new calculations have to be performed, new safety studies etc. It would be cost-saving if a ‘smart module’ will be used within boundaries. Even production process will benefit and can be reproduced in a clean environment. No dirty building sites with dangerous situations anymore. At last the lifecycle of the modules (materials) will be extended. Nowadays a LQ is designed for 15 years.

In the following chapters the design will have the figures of the ‘smart module’ (#32, #33, #34).

**Structural**

For the structural design the rules will be used from Det Norske Veritas (DNV), offshore containers year 2006. DNV is an autonomous and independent foundation with the objectives of safeguarding life, property and the environment, at sea and onshore. DNV undertakes classification, certification, and other verification and consultancies services relating to quality of ships, offshore units and installations, and onshore industries worldwide, and carries out research in relation to these functions. Following constrains are taken from the DNV rules:

1) General

The intention is that offshore containers shall meet the following requirements:

- be safe in use with regard to:
  - lives
  - environment
  - hazard to the vessel/installation

Be suitable for repeated use through choice of:

- material
- protection
- ease of repair and maintenance.

- They are lifted individually by crane hook attached to top link of lifting set
- They can be lifted anywhere (worldwide) by any crane with sufficient capacity and speed
- They are only stacked if they are designed for this.

2) Offshore container

An offshore container is a portable unit with a maximum gross mass not exceeding 25 000 kg, for repeated use in the transport of goods or equipment, handled in open seas, to, from or between fixed and/or floating installations and ships. An offshore container comprises permanently installed equipment,
#33: Platform situation

#34: Lifting situation
3) Primary Structure
Load carrying and supporting frames and load carrying panels. Primary structure includes the following structural components:

- Load carrying and supporting frames
- Load carrying panels (floor, ‘tweendecks)
- Fork lift pockets
- Pad eyes
- Supporting structures
- Corner/knee brackets.

Primary structure is divided into two sub-groups:

a) Essential and non-redundant primary structure are the main structural elements which transfer the resulting cargo load to the crane hook or fork lift truck (i.e. forming the load path from the payload to the lifting sling), and will at least include:

- top and bottom side rails
- top and bottom end rails
- corner posts
- pad eyes
- fork lift pockets.

Other primary structure may also be considered essential and or non-redundant.

b) Non-essential primary structure are e.g. floor plates and other structural elements for which the main function is other than described in a). Deflector plates, stacking fittings and end plates on hollow section are considered to be in this category. This sub-group also includes protective frame members.

4) Secondary Structure
Parts that are not considered as load carrying for the purposes of the design calculations. Secondary structure includes the following components:

- Doors, wall and roof panels, covers on skids
- Panel stiffeners and corrugations

5) Steel
Extra high strength steels, with specified yield stress above 500 N/mm², shall not be used. Structural steels for primary structure shall be carbon steel, carbon-manganese steel, carbon–manganese micro-alloyed steel or low-alloyed steel.

6) Aluminium
The chemical composition, heat treatment, weldability and mechanical properties shall be suitable for the purpose. When materials of different galvanic potential are joined together, the design shall be such that galvanic corrosion is avoided. Aluminium used in offshore containers shall be wrought alloys, i.e. be made by rolling or extruding.

7) Non-metallic materials
Timber, plywood, fibre reinforced plastics and other non-metallic materials shall normally not be used in primary structures, but may be used in secondary structures. Due regard shall be given to strength, durability, suitability and possible hazards caused by use of these materials.

8) Structural design
Containers shall be designed as structural frames (primary structure), with non-load bearing cladding where necessary (secondary structure). Only the primary structure shall be considered in the design calculations. However, on waste skips with trapezium shaped sides and with open top or only a non-stressed cover above the bracing where the pad eyes are attached, the whole structure may be considered as primary structure, and the skip may be calculated as a monocoque construction.

All connections between frame members and between pad eyes and frame members shall be designed to give good continuity. Where beams of different cross sections meet, they shall normally be aligned as far as possible, and measures shall be taken to minimize stress concentrations on webs or flanges.

Offshore containers may be constructed with partly removable primary structure. Bolted or pinned connections will be specially considered with regard both to strength and securing. Removable beams, walls or covers shall be secured in such a way that they will not fall off even if a securing device is damaged.

9) Lifting loads
No deflections during testing shall be greater than 1/250 of the span of the member. The container shall show no significant permanent deformations or other damages after testing.

As written above general rules are written for steel (aluminium) structures. There is not a written regulatory available for only fibre reinforced construction. Lack of knowledge and the long testing period needed can be one of the reasons.
### AREA LIMITS

<table>
<thead>
<tr>
<th>Room or space</th>
<th>Vibration limit</th>
<th>Noise Total</th>
<th>Noise HVAC dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corridors</td>
<td>1</td>
<td>60</td>
<td>50</td>
</tr>
<tr>
<td>Offices/meeting</td>
<td>1</td>
<td>45</td>
<td>40</td>
</tr>
<tr>
<td>Toilets</td>
<td>1</td>
<td>60</td>
<td>50</td>
</tr>
<tr>
<td>Changing rooms</td>
<td>1</td>
<td>45</td>
<td>40</td>
</tr>
<tr>
<td>Recreation rooms</td>
<td>1</td>
<td>45</td>
<td>40</td>
</tr>
<tr>
<td>Cabins</td>
<td>1</td>
<td>40</td>
<td>35</td>
</tr>
</tbody>
</table>

#35: Sound requirements Norsok S-002

#36: Low tech

#37: Medium tech

#38: High tech
**Acoustic**

Structure borne noise has its origin in the structure and can therefore travel as an energy form throughout the structure of a vessel/building/etc. Structure borne noise is generated at the mounting positions of a machinery piece (e.g. engine feet with or without resilient mounts) or by extreme loud airborne noise which ‘irradiates’ in the structure. Structure borne noise is more difficult to dampen compared to airborne noise and can travel greater distances.

Airborne noise has its origin at a source which is radiating (pulsating) energy in its surrounding medium, normally air (engine block for example). Airborne noise is mainly important in outdoor areas and in locations next to rooms where a source is located, for example a generator next to the module or noise transfer from cabin to cabin. Airborne noise is a large contributor to the overall noise level inside a module.

Airborne noise sound reduction is expressed by a standard single number notation, Rw or STC (e.g. Rw 55 dB). Both notations focus on human speech/music and has its origin in the building industry. They focus on frequency bands from 100/125 Hz to 3150/4000 Hz. An Rw/STC standard graph contour is shifted over the airborne noise reduction performance of a partition (wall) until certain criteria are met. These criteria include a maximum difference (performance loss compared to the standard graphical contour) and an average difference.

Consideration should be given to the acoustic insulation between accommodation spaces in order to meet the requirements in Norsok S-002, table 6.1.0.0-1 (#35) even if the activities are going on in adjacent spaces, e.g. music, talking, etc. It should be noted that the human factor as a noise source can not be taken in account, therefore the sound reduction values stated in Norsok S-002, table 5.5.3.0-4 will be guiding. The following sources must be taken into account during the design phase.

- Helicopter take off/landing.
- Operational and Working Environment Noises.
- Internal noise from HVAC systems.
- Noise from Water & Waste systems.
- Television, Music & Conversations in adjacent spaces. See table on the left for noise limits for each area.

For all external noise sources 85 dB(A) at 1m from the outside of the accommodation will be assumed. Rw should then be minimum 45dB(A)

**Thermal**

The insulation should have a U-value not exceeding 0.50 W/(m²K). The insulation shall be laid in such a way that condensation is avoided and shall be securely fastened.

**Fire resistant**

For all living quarters the external boundary should be A60 rated. Definition of A60:

“A60” class divisions should be insulated with approved non-combustible materials such that the average temperature of the unexposed side will not rise more than 140°C (250°F) above the original temperature, nor will the temperature, at any one point, including any joint, rise more than 180°C (324°F) above the original temperature, within the 60 minutes.

4.2 SCENARIOS

To come to a good realistic design the following scenarios have been set up.

1) low tech (building, furniture) non-structural (skel-eton), components (composite)
2) medium tech (bridges, ships) partly structural (com-posite panels)
3) high tech (airplane, aerospace) structural (monocoque)

Each of the scenarios will be explained hereafter by their (preliminary) specific advantages and disadvantages within the boundary conditions given before in the previous chapters. By a value assessment, where each scenario will get points and a price/weight comparison, a choice will be made for the scenario to continue with.

**Low tech (#36)**

In this scenario a structural skeleton will be filled with (non-structural) sandwich panels. The skeleton can be of different materials; steel, aluminium or FRP. Within these materials variety can be found in there composition with their specific weight and price.

For the sandwich panels it is necessary that they will be constructed so to comply to the technical requirements. For this panel lots of different compositions are possible and therefore careful research should be done to the different kind of materials. The integration of the panels into the skeleton is a challenge with the focus on water tightness and fire-performance.
### VALUE ASSESSMENT

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Comp Mono</th>
<th>Comp + Comp</th>
<th>Steel + Comp</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lifting</td>
<td>4</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Transport</td>
<td>4</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Weight</td>
<td>5</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Production process (hours)</td>
<td>3</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Production process (costs)</td>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Fire resistance</td>
<td>3</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Machinability</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Penetrations</td>
<td>2</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Safety</td>
<td>2</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Damage control</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Recyclable</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Environmental</td>
<td>2</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Supports, foundations, clamps</td>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Connections between</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Calculations</td>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Maintenance</td>
<td>4</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Construction time</td>
<td>4</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>53</strong></td>
<td><strong>57</strong></td>
<td><strong>60</strong></td>
</tr>
</tbody>
</table>

*Values are based on applicable data and can be an assumption if information is not yet known.

---

### SCENARIO

<table>
<thead>
<tr>
<th>Scenario</th>
<th>x Euro</th>
<th>y kg</th>
<th>Euro/kg</th>
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</thead>
<tbody>
<tr>
<td>Existing module</td>
<td>1</td>
<td>1</td>
<td>1,00</td>
</tr>
<tr>
<td>1) Skeleton + FRP panels</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- steel</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>hot rolled</td>
<td>1,25</td>
<td>0,85</td>
<td>1,47</td>
</tr>
<tr>
<td>cold rolled</td>
<td>1,4</td>
<td>0,825</td>
<td>1,70</td>
</tr>
<tr>
<td>high strength</td>
<td>1,4</td>
<td>0,825</td>
<td>1,70</td>
</tr>
<tr>
<td>aluminium</td>
<td>1,35</td>
<td>0,81</td>
<td>1,67</td>
</tr>
<tr>
<td>extruding/welded</td>
<td>1,6</td>
<td>0,92</td>
<td>1,74</td>
</tr>
<tr>
<td>extrusion/casting</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FRP</td>
<td>1,4</td>
<td>0,85</td>
<td>1,65</td>
</tr>
<tr>
<td>2) Structural panel (KIP)</td>
<td>2</td>
<td>0,7</td>
<td>2,86</td>
</tr>
<tr>
<td>3) Structural monocoque</td>
<td>2,2</td>
<td>0,65</td>
<td>3,38</td>
</tr>
</tbody>
</table>

*Goal: - 15-20% weight / +10-15% total costs

Units: 1000
Advantages
• short construction time
• use of in-house knowledge (for steel, aluminium)
• non-structural panels (penetrations), only for stability
• certification (only on standard panel)
• Easy replaceable panel in case of damage

Disadvantages
• connections
• water tightness

Medium tech (#37)
This scenario exists of structural sandwich panels. It’s almost like the children’s toys Lego and Play mobile. Elements can be ‘clicked’ in each other forming a building. A variant in this scenario is the folding method.

Advantages
• weight
• simple (re)production method

Disadvantages
• structural skin (penetrations)
• need for knowledge
• connections/details?
• Project certification
• Damage (control)

High tech (#38)
In this scenario the building is a monocoque system. By the use of a mould the walls, roof and floor will be one complete structural component (like an egg) No difficult connection details or problems with water tightness. Weight will be less than other scenarios; however the structural property can cause weight increase. Special care should be taken for the structural skin with respect to penetrations and damage (like crack in an egg). A solution could be to create certain places in the construction where penetrations are possible.

Advantages
• less weight
• certification for one typical module

Disadvantages
• structural skin (penetrations)
• need for knowledge

• high costs (mould)
• damage (control)

Conclusion
A challenge for all scenarios is the 3D corner, where the sides meet each other. In the value assessment each scenario will get points for the parameters that are of interest in this design (#39). Out of this table it can be concluded that scenario one gets the most points. Also on the left a comparison of the weight versus price for each scenario can be found (#40).

The choice has been made for scenario 1.

The sandwich construction in combination with the structural frame will give more stability, and therefore safety, especially in case of a fire.

Hertel offshore; ‘we would like to have scenario 3, but because of lack of knowledge for FRP and the high demands lets do it step by step, beginning with scenario 1. We can still use our in-house knowledge and make an innovative step in the conservative offshore industry’.

‘To design, as to live is to change, and to aim for perfection is to have changed often’
#41: Panel fixing

## LOADS

<table>
<thead>
<tr>
<th>self weight</th>
<th>m x g</th>
</tr>
</thead>
<tbody>
<tr>
<td>roof</td>
<td>1.5</td>
</tr>
<tr>
<td>floor</td>
<td>3</td>
</tr>
<tr>
<td>wind operational</td>
<td>1.25</td>
</tr>
<tr>
<td>wind survival</td>
<td>2.5</td>
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</table>

#42: Weight per discipline

## MATERIALS

<table>
<thead>
<tr>
<th>type</th>
<th>yield strength (N/mm²)</th>
<th>Young's modulus, E (GPa)</th>
<th>Poisson ratio</th>
<th>density (kg/m³)</th>
<th>Elongation (%)</th>
<th>G modulus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>5235</td>
<td>235</td>
<td>0.3</td>
<td>7800</td>
<td>3 up to 40</td>
<td>80</td>
</tr>
<tr>
<td>Aluminium alloy</td>
<td>6083 T6</td>
<td>250</td>
<td>0.34</td>
<td>2700</td>
<td>1 up to 45</td>
<td>30</td>
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<tr>
<td>GRP</td>
<td>glassfibre laminate</td>
<td>270</td>
<td>0.1</td>
<td>2000</td>
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<tr>
<td>Cork</td>
<td>natural</td>
<td>1.4</td>
<td>0.32</td>
<td>250</td>
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<td>0.005</td>
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<tr>
<td>Rockwool</td>
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<td>1.3</td>
<td>0.03</td>
<td>100</td>
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<td>0.005</td>
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<tr>
<td>PU</td>
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<td></td>
<td></td>
<td>1050</td>
<td></td>
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</tbody>
</table>

#43: Weight per discipline
4.3 DESIGN

Functional

The dimensions of one module is 10m (l) x 4m (w) x 3.5m (h). The panels could be installed in several ways (#41).

1) panels can be in between the skeleton (columns) and therefore stay within the ISO frame. This is only applicable for steel, because other materials need insulation in front of the skeleton because of a lower melting point and certification.

2) If the skeleton is made of aluminium or FRP panels could be glued to the skeleton. However the panels are not removable anymore.

3) In the third option panels will be bolted against the frame, so they are removable. Consequences are that the corners should be covered with insulation afterwards.

To save weight all construction parts that are not really necessary will be taken out. When stacking modules on each other a roof and floor will be on top of each other. As a dividing part this is a double construction. Options are to leave the floor or roof out. To be able to install all the interior materials (wall, furniture etc) there is chosen to delete the roof construction. Also side walls will be taken out because they are functionally not necessary and it is an obstruction for creating large spaces.

Structural

The skeleton could be made of several materials; steel, aluminium or FRP. Because walls and roof are taken out, stability will be solved by temporary bracings (in compression or tensile strength). In this research a small study is performed for the skeleton in combination with a front and back wall made of FRP-cork-FRP. Cork is chosen because of their interesting material properties derived from the reference materials study (chapter 3, Corecork).

In this preliminary design a material research will be performed for the skeleton with their specific weight, stresses and deformation. Next the position of bracings, strips or tubes, will be looked into to take care of the stability. The fact that the modules must be able to be stacked a study will be done for the stability and connection in between the modules. At last a decision will be made for the material type, and the way of construction.

At first main dimensions must be determined. Out of the functional requirements the module will have dimensions of:

- Width: 4000mm
- Length: 10000mm
- Height: 3500mm

For the skeleton it is preferred to use tubes, because of material handling (easy cutting and welding). I-profiles can however decrease the weight but cutting, coping and more welding are not preferred, or be kept to a minimum.

Total composition of the wall and floor panels is:

- FRP-Cork-FRP
- 4mm + 60mm + 4mm (total 68mm)

The connection between the layers is considered fixed. The possibility of de-lamination should be performed in a more detailed study.

Load cases can be found in the table on the left (#42). Wind load is the most extreme wind that will occur in 100 years.

Maximum deformation according DNV for all load cases combined is:

- \[ U = \frac{1}{250} \]
- (maximum is 10000 / 250 = 40mm)

Materials used can be found in the table on the left (#43).

According to the AISC rules (referred to in DNV) maximum stress allowed is:

- normal stress \( x,y < 0.6 \times \text{yield} \)
- bending stress \( 0.66 \times \text{yield} \)
- shear \( 0.4 \times \text{yield} \)

Implemented in the formula:

- STEEL (355) \( \text{normal stress } x,y < 213 \)
  \( \text{Shear} < 142 \)

- ALU (500) \( \text{normal stress } x,y < 300 \)
  \( \text{Shear} < 200 \)

- FRP glassfibre unidirectional profile(1150) \( \text{normal stress } x,y < 690 \)
#44: Steel, maximum tension 113N/mm²

#45: Steel, maximum deformation 13,5

#46: FRP, maximum deformation 36,5 mm

#47: Steel, maximum deformation 52 mm
All connections are fixed. For the support on the platform the modules will be welded or bolted fixed to the deck.

- **Steel**
  - max normal stress x,y < 113 (#44)
  - max shear < 15,1
  - max deformation 13.5 (#45)
  - weight: 3684kg (Basis)

- **Aluminium**
  - max normal stress x,y < 101
  - max shear < 13,7
  - max deformation 21,9
  - weight: 3131kg (-553)

- **FRP**
  - max normal stress x,y < 98,3
  - max shear < 13,6
  - max deformation 36,5 (#46)
  - weight: 3028kg (-656)

**Stability**
To eliminate weight and because of functional reasons the roof is taken out and side walls will be bracings (or strips) that can be taken out when necessary/possible. End modules on the side or on top will need to be closed with panels afterwards. To ensure stability of the structure three situations are studied: tubes (compression), strips (tensile), bracings (tensile).

**Lifting**
The maximum deformation during lifting is 52mm (#47). Is not correct.

**Conclusion**
Out of the calculations it can be noted that the FRP variant is lighter than steel and aluminium. However, the deformations found are not acceptable. The FRP beams need to be reinforced by a different type of fibres (other than glass) or reinforcement plates. This will have consequences for the weight. The weight can be optimum if the fibres are in the same direction as the tensile stresses. However for compression the FRP beams are dependent on the resin (bonding). Besides the calculation it still needs more investigation with respect to aging, fire resistance and damages, especially because it is the main construction. Also the production process is still slow and costly.

The biggest step in weight loss can be found from steel to aluminium. Stresses and deformations are within the rules. Other advantages of aluminium are the fact that it is corrosion/maintenance free, reliable and available in diverse profiles.

For the horizontal deformation the wind load is decisive. The stiffness of the wall panels should therefore be changed. The floor turns with the deflection of the wall, and together with the floor load itself it becomes a waving plate. The best way to prevent this is to increase the thickness of the core. By doing this the moment of inertia will grow and therefore the stiffness.

Normal stresses are not the main problem. In all cases they comply to the rules, however during this study material yield strength for aluminium and FRP are high and need to be changed according to the correct aluminium alloy (applicable for offshore) and FRP direction of the fibres. The most critical issue is the deformation of the module.

For stability strips (flat plate) are preferred, because of weight performance and material handling. More study is needed to ensure the strips are sufficient during the way (transport) from construction phase to the situation in place.
#48: Transport large LQ

#49: Transport smart module

#50: Transportation of small modules nowadays
4.4 TRANSPORT
Transportation of the modules needs extra attention with respect to costs involved and the specific route. A large LQ of 200,000kg, 4 storeys high, dimensions 20m x 10m will be compared with 20 smart modules with a weight of maximum 10,000kg, 1 storey, dimensions 10m x 4m.

1x Large LQ
Building a large LQ start at a mostly expensive (rented) building site. Besides this it is a dirty side where extra security is needed. Transporting the module to the river side must be done by multi wheelers. Because of the weight a crane-boat must be hired to lift the LQ on the supplier and later on upon the platform. When the LQ is on its place it can function (plug and play principle). The transport only will cost approximately Euro 190,000 (#48).

20x Smart module
The benefit of small containers already start in the production phase. Because of its dimensions it can be build in a clean environment with good quality control. After production the modules can be easily lifted on a truck and transported to the river side. Using the small crane again the modules will be placed on the supplier. Every platform has its own crane for small food containers. However these cranes can now be used to lift the modules on its place. After positioning the smart modules should be connected easily forming a large LQ. The transport only will cost approximately Euro 170,000 (#49).

Nowadays when small modules are shipped to the platform it is difficult to move them because of many obstructions (#50). Therefore the platform design must be changed and take into account the position for smart modules, so the POB can change (flexibility).

4.5 CONCLUSIONS
Panels will be made of FRP and will take care of the stability of the skeleton. The skeleton will be made of aluminium. Both FRP and aluminium are ‘clean’ materials and therefore give effort in the production phase.

Installation or removal of the panels should be possible from the inside. Offshore scaffolding is not ideal, because of safety and expensive man-hours.

Use the production method of aluminium profiles for a smart profile instead of a standard (derived from steel) tube.

Benefits for transport are minimal but should be found in the (clean) production method, quality control and the flexibility of the design.
#51 Transport; maximum deformation 9.49mm

#52 Transport; maximum tension 27.5N/mm²

#53 Lifting; maximum deformation 35.5mm

#54 Lifting; maximum tension 51N/mm²
5. CONSTRUCTION RESEARCH

In this research the design will be calculated on strength, stiffness and stability. With the help of Diana, a Finite Element Methode (FEM) program, research will be done for the stresses and deformations that will occur in the construction. The following scenarios will be calculated: construction phase, transport, lifting, in place and at last in detail one panel in a frame. In addition to these scenarios a hand calculation will be performed for the pad eye during lifting situation and buckling of the aluminium skeleton. When all this scenarios comply to the general offshore rules a more detailed design can be made with the correct dimensions.

Load cases can be found in TABLE
Wind load is the most extreme wind that will occur in 100 years. Normally 1.25kN/m2.
Maximum deformation according DNV for all load cases combined is:

\[ U = \frac{1}{250} \]
(maximum is 10000 / 250 = 40mm)

Materials used can be found in TABLE
According to the AISC rules (referred to in DNV) maximum stress allowed is:

- normal stress \( 0.6 \times \) yield
- bending stress \( 0.66 \times \) yield
- shear \( 0.4 \times \) yield

Implemented in the formula:

**STEEL (355)**
- normal stress \( x,y \) < 213
- Shear < 142

**ALU 6083 T6 (250)**
- normal stress \( x,y \) < 150
- Shear < 100

**FRP glassfibre fabric (270)**
- normal stress \( x,y \) < 162
- Shear < 108

In the preliminary design different kind of aluminium tubes were used. In this calculation only shs 100x100x4 has been chosen for the skeleton. It is preferred to use one type of (extrusion) profile to prevent high costs (mould) and material handling.

For the composition of the panel cork as core material can perform well, but it is not easy available. Therefore a cheaper, easy available and already A60 fire-rated Rockwool will be implemented. Out of the previous calculation the thickness of the floor is increased to create more stiffness.

Total composition of the wall panel is:
FRP-Rockwool-FRP
4mm + 60mm + 4mm (total 68mm)

Total composition of the floor panel is:
FRP-Rockwool-FRP
4mm + 120mm + 4mm (total 128mm)

5.1 CONSTRUCTION PHASE
During construction the module should be able to stand alone. However temporary studs and/or bracing are normally used till the module is ready for transport. Ready for transport, means that the bracings and wall panels are installed so the module is stable.

5.2 TRANSPORT
Transport of the modules will be executed by trucks and boat. The most extreme situation by truck will be an emergency break. In this calculation the G-force is rotated to the y-direction, even 3G! The module is fixed on the four corners. The displacement is 9,49mm in the top girder (<40mm, Correct)(#51). Maximum stresses are in the bracings. It can be noted that tensile stress occurs of 27,5N/mm². Compression in the other strip is not preferred and will be taken over by the other strip, so maximum stress will be 2 x 27,5N/mm² = 55N/mm² (<150N/mm², Correct)(#52)

5.3 LIFTING
Lifting can be performed in several ways. In this calculation a single lift and lifting by means of a lifting frame will be studied. It can be noted that the floor will be carried by the strips only when the top rail is stiff enough and will not buckle. This can be clearly seen in PICTURE, the floor will wave. The maximum deformation is (LC01) 35,5mm +(LC02) 0mm = 35,5mm (<40mm, Correct)(#53).
#55 $2=2$; maximum deformation 32mm

#56 $2=2$; maximum tension 74,4N/mm²

#57 $4=4$; maximum deformation 38mm

#58 $4=4$; maximum tension panels 32N/mm²

#59 No panel; maximum deformation 58,4mm

#60 No panel; maximum tension 58,7N/mm²
For the maximum stresses again the strips will do what they do best. They are loaded in tensile stress of 51N/mm² (<150N/mm², Correct)(#54).

For buckling an additional beam is added to shorten the length of 10000mm. Buckling will be checked later in this study.

5.4 IN PLACE
For the situation in place the constraint is: quantity modules x = quantity modules y, with a maximum height of 4 modules. Two situations (minimum and maximum) are analysed:
- 2 modules width = 2 modules stacked
- 4 modules width = 4 modules stacked.
The connections between the modules are M20 aluminium bolts only in the corners.

2 = 2
The maximum deformation is (LC01) 28mm +(LC02) 4mm = 32mm (<40mm, Correct)(#55).
The maximum stress due to the wind load is 2 x 24,8= 49,6 N/mm² (<150N/mm², Correct).
The maximum stress due to the floor load, found at the strips, is 74,4N/mm² (<150N/mm², Correct)(#56). This means the floor is hanging by strips distributed to the roof beam that is in compression (buckling can occur).
The shear forces found in the panels are 15,8N/mm² (<108N/mm², Correct).

4 = 4
The maximum deformation is (LC01) 33mm +(LC02) 5mm = 38mm (<40mm, Correct)(#57).
The maximum stress due to the wind load is 2 x 24,8= 49,6 N/mm² (<150N/mm², Correct). The maximum stress due to the floor load is 74,4N/mm² (<150N/mm², Correct). This means the floor is hanging by strips distributed to the roof beam that is in compression (buckling can occur).
The shear forces found in the panels are 32N/mm² (<108N/mm², Correct)(#58).

It can be seen that the wall panels function like a beam. On the bottom tensile stress occur and on top compression. However a compression of 78,8N/mm² can cause wrinkling of the panel.

5.5 PANEL
In this scenario the connection of one panel in an aluminium frame will be discussed. Three types of connections are calculated: no panel, fixed panel and a clamped panel. A local force is applied in the top left corner of 2.5kN (f.e. damage). The bottom corners are fixed. Top corners are fixed only in the z-direction.

No panel
Deformation is mm. (4000/250=16mm, not correct)(#59).
The stresses are 58,7N/mm² (<150N/mm², Correct)(#60).

Fixed panel
Deformation is 0,12mm. (4000/250=16mm, Correct). This proves that the sandwich panel stabilizes the construction. The shear stresses in the skin of the structural panel are 0,211N/mm² (<150N/mm², Correct). The stresses are directly 'diving' in the sandwich panel (#61).

Clamped panel
The connection between the frame and panel is translated into a slave-master principle. This means that on certain points the panel has a degree of freedom (d.e.f.) only in the given direction. In this situation the panel and column has a d.e.f. in the y-direction. For the top and bottom rail the panel has a d.e.f. in the x-direction.
Deformation is almost 0,156mm. (4000/250=16mm, Correct)(#62).
The stresses are 1,19N/mm² (<150N/mm², Correct)(#63).
For the wind load of 2,5 kN/m² a maximum deformation of 25,7mm (#64) is found and shear stresses of 2,25N/mm² (#65).

Because the inside of the wall is the end surface of the space behind, this is not ideal. However in a storm situation most important is the building will not collapse and damages should be kept to a minimum.
The stresses are fluently going in the sandwich panel. The calculation shows that the shear stress occur in both the skin materials (FRP), whereby the core material just functions as a in between layer that holds the two skins.
#61 Fixed panel; maximum shear 0.211N/mm²

#62 Clamped panel; Wind load, maximum shear 2.25N/mm²

#63 Clamped panel; maximum shear 1.19N/mm²

#64 Clamped Panel; wind load maximum deformation 25.7mm

#65 Clamped panel; impact load maximum deformation 0.156mm

#66 Padeye
together. This emphasizes that the connection (glue) between these layers must be reliable, and should be tested and calculated in detail.

5.6 PADEYE

**Input**

- Green pin 12 ton (bolt diameter = 35mm)
- Weld throat 8
- Safety factor 4
- Weight max 100kN (4 padeyes/4 = 100kN each padeye)
- Lift 60°
- Plate A5083 H22 (Y=215) 20mm thickness
- δ stress = F / A
- W = 1/6*b*h^2
- Dimension see bottom left (#66)

**Calculation**

δ bending = M / W

(87*10^3  x  75) / (1/6*20*175^2) = 63.9 N/mm²

(5% out of plane) (4.35*10^3  x  75) / (1/6*175*20^2) = 28 N/mm²

δ shear = F / A*2

(100*10^3) / (55*20*2) = 45.45 N/mm²

δ shear xx= Fy / A*2

(87*10^3) / (55*20*2) = 39.5 N/mm²

δ stress yy= Fx / A

(50*10^3) / (150*20) = 13.3 N/mm²

δ bearing pressure xy= Fxy / A

(100*10^3) / (40*20) = 125 N/mm²

**Weld**

δ bending = M / W

(87*10^3  x  75) / (1/6*8*175^2)*2 = 80 N/mm²

(5% out of plane) (4.35*10^3  x  75) / (1/6*175*8^2)*2 = 125 N/mm²

δ shear xx= Fy / A*2

(87*10^3) / (150*8*2) = 36.3 N/mm²

δ shear yy= Fx / A*2

(50*10^3) / (150*8*2) = 20.8 N/mm²

δ shear combine = √ (δ shear xx² + δ shear yy²) √ (36.3² + 20.8²) = 41.8

UC = 41.8 / 86 = 0.49

(check ≤ 0.66*Y= 142)

(check ≤ 0.4*Y= 86)

(check ≤ 0.4*Y= 129)

(check ≤ 0.6*Y= 129)

(check ≤ 0.4*Y= 86)

(check ≤ 0.4*Y= 86)

(check ≤ 0.4*Y= 86)

(check ≤ 0.4*Y= 86)

(check ≤ 0.66*Y= 142)

(check ≤ 0.4*Y= 86)

(check ≤ 0.4*Y= 86)

(< 1, Correct)
5.7 **BUCKLING**

Out of the previous calculations a spreader beam can be used. However in a single lift the top rail will function as a spreader beam. Due to compression a beam can buckle. To prevent this the length should be decreased by an additional support or increase the compression strength (more mass).

**Input**

- Youngs Modulus (E) aluminium: 70000 N/mm²
- Spreader Length (L): 10000mm
- Area Spreader: 1536,00 mm²
- Moment of Inertia, (Iₓ): 2,36E+06 mm⁴
- Section Modulus: 4,73E+04 mm³
- Sigma Compression (C): 29,30 N/mm² (PICTURE LIFTING)

**Calculation**

Effective length factor (K): 0,8 (AISC effective length)

Radius of Gyration (r): (Iₓ/area)^(0,5) = 39,23

\[ \sigma_{\text{critical}} (L:1000mm): \]

\[ F_{cr} = \frac{\pi^2 \times E}{(KL/r)^2}: \boxed{16,61} \text{ N/mm}^2 \text{ (maximum compression for buckling)} \]

(check \( \leq 29,3 = \text{Incorrect!} \))

Maximum tension for buckling is exceeded. To minimize the compression an additional beam can be added to shorten the length. New spreader length is: 6000mm.

\[ \sigma_{\text{critical}} (L:6000mm): \]

\[ F_{cr} = \frac{\pi^2 \times E}{(KL/r)^2}: \boxed{46,15} \text{ N/mm}^2 \text{ (maximum compression allowed for buckling)} \]

(check \( 29,3 \leq = \text{Correct} \))

SF for buckling is \( C / F_{cr} = 0,63 \)

(< 1, Correct)
#67 Panel conditions

#68 Different layers with their performances
6. PANEL

The (facade) will be described in this chapter. First the composition will be explained by the material used and their behaviour. Secondly the assemblage is studied and will be discussed by type.

6.1 COMPOSITION

The outside panel (facade) of the LQ should have the following performances(67):

- fire resistant
- thermal value >0.5
- wind
- rain
- temperature (differences)
- sound (helicopter)
- blast (pressure)

The idea for this (high) performance panel is to create a sandwich panel that would succeed in all these requirements. At first a fixed sandwich was in mind, but after further study the idea came up to 'split' the sandwich in two parts. One part is the 'structural' part and the second part the 'sound/blast' part. To minimize the moment of force the structural sandwich part is close to the construction side. The 'sound/blast' part will be on the outer side, close to the noise/blast sources.

Structural part

The structural part will be a sandwich construction made of a core material (insulation) with on both sides a FRP skin. The principal of a sandwich is to create a distance between the two skins and therefore increase the strength of the panel. By using a lightweight core material a total lightweight panel will be achieved with excellent strength performances.

Sound/blast part

In this part a cavity will be filled with (soft) acoustic material. Because of the mass spring coincidence effect the cavity could be changed if necessary, using the mass of the structural panel and the outer layer made of FRP. In the sandwich idea, the different layers should be a benefit for sound reduction. The idea is to lift up the coincidence effect of one layer, by the other layers, where the coincidence effect takes place in another frequency. In addition to this principle a sound mat is introduced. By friction, energy will be transformed to heat and therefore perform as a sound reduction. The Promasound matt will especially be good for the low frequencies (helicopter).

By using a thin outer layer of FRP the skin is able to deform in the cavity in case of a blast pressure. In this case the structural part will not be damaged and is still able to stabilize the construction.

Total construction

The total construction will be used for fire and thermal performance. The structural part will have a certified A60 insulation core material to guarantee the inner temperature will not rise more than 140°C (250°F) above the original temperature. However before reaching the structural panel the acoustic insulation will help to decrease the time and temperature of the fire. For the thermal behaviour all layers will contribute to decrease the R-value. To keep the total sandwich maintenance free the outer layers are made of FRP to withstand wind, rain or dirt (68).

6.2 ASSEMBLAGE

To assemble the panel into the structural frame several options are studied. Welding and glueing are not ideal because the panel should be possible to be substituted. Therefore the following fixing methods are studied:

- bolted
- hanging
- clamped

The way the panel will be fixed to the construction will have consequences for the structure profiles. The panel and the profiles can not be handled apart from each other. For each fixing method the development of the profile will be described.

Bolted

When bolting will be used the panel could end with an angled profile where bolts can be put through (69) against the column. As described before an aluminium structure should be insulated from the outside. When using these angled profiles the open spaces should be covered afterwards. For the roof however these openings can be used as a gutter for rainwater (70). However after discussion with the construction side it is not preferred to spend many hours offshore for assemblage due to the costly man-hours for bolting and scaffolding (71).
#69 Bolted panel type

#70 Bolted type, gutter

#71 Bolted type, insulation covers

#72 Development of the aluminium profile
**Hanging**

As an alternative an hanging construction is studied. In this way time can be saved and less/no bolting is necessary. However tolerances has to be taken in account to make the assemblage possible. Difficulties could occur with sealing and closing off open spaces.

**Clamped**

The last alternative is a clamped construction. Because aluminium has a wide range of profiles the idea came up to integrate the construction method in the profile. With the clamp construction the panel can be placed in front of the skeleton and does not need any tolerances (space). The small profile attached to the sides of each panel will 'fall' in the opening in the construction profile. A slide will clamp the small profile against the column (#72).

**Detail**

To eliminate high costs for many different types of panels there should be a logical link/assemblage principle. The wall panels consist of type A and type B (=type A mirrored). Between the panels an A60 rubber profile will be laid that fits and connects type A and B together. For the roof and floor panel the same principle should be used. To prevent water to enter the building the same rubber profiles will be used and the slope will be towards outside.
#73 Promasound sound performance

#74 Sound performance according mass law
7. PERFORMANCES

In this chapter the performances of the panel will be (theoretically) predicted. The main focus will be on acoustic, thermal and fire behaviour of the wall construction. Acoustic and thermal behaviour will be described with several calculations and diagrams. Only for the fire-resistancy of the panel recommendations will be given how to reach up the A-60 value. For real figures a fire-test should be performed.

7.1 ACOUSTIC

In general the maximum allowed sound level in cabins due to outside ‘normal’ noise is 40dB(A). The expected ‘normal’ noise level in front of the façade is 85db(A), 1 meter distance. During helicopter landings and take offs a noise level in front of the façade can reach up to 90dB(A), 1 meter distance.

According to the mass law, mass is needed for the low frequencies. This is in contradiction with the idea of a lightweight module.

An idea is to use water. Water with his specific weight can be perfectly used for the low frequencies. In transport the hollow spaces (cassettes) can be empty and in place and in use the space can be filled with water. At the same time this water can be used in case of fire!

By using FRP for the skin it is expected that noise reduction will be achieved by reflecting and redirecting of the offending sound waves. The second layer should be a cavity or cavity filled with absorption material. Total thickness is 50mm. The third layer consists of Promasound (Promat) with a thickness of 4mm (includes certificate with Rw 39dB!)(#73). This mat is a visco-elastic product with low fire and smoke spread, MED certificate. Promasound has a low E-modules and a high mass. The mat will be fixed only on certain points (it will be a hanging mat) and together with the low E-modulus it is expected coincidence effect will not occur.

For normal situations the spectrum below can be used.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>63</td>
<td>67</td>
</tr>
<tr>
<td>125</td>
<td>82</td>
</tr>
<tr>
<td>250</td>
<td>83</td>
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<td>500</td>
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<tr>
<td>2000</td>
<td>75</td>
</tr>
<tr>
<td>4000</td>
<td>68</td>
</tr>
<tr>
<td>8000</td>
<td>57</td>
</tr>
</tbody>
</table>

The maximum helicopter noise levels are expected to be approximately 80 dB(A) at the module. The spectrum shown below can be used. In practice, this spectrum is assumed to be conservative, particularly around 125 Hz band.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>63</td>
<td>52</td>
</tr>
<tr>
<td>125</td>
<td>90</td>
</tr>
<tr>
<td>250</td>
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<tr>
<td>2000</td>
<td>57</td>
</tr>
<tr>
<td>4000</td>
<td>45</td>
</tr>
<tr>
<td>8000</td>
<td>24</td>
</tr>
</tbody>
</table>

**Input**

- Rockwool: 100kg/m3
- FRP: 1600 kg/m3
- Promasound: 2100 kg/m3
- speed of air: 340 m/s
- density of air: 1.21 kg/m3

**Calculations**

Coincidence effect (for single layer)

\[
\text{Coincidence} = (1600) \times \sqrt{\frac{E}{\rho}} (d)
\]

Sound reduction mass law:

\[
R_{500} = 20 \log \left( \frac{2\pi f m^2 \rho}{2 \rho c} \right)
\]

The coincidence effect for a cavity wall construction will occur because of the mass-spring resonance. For an A-symetric cavity (max 2 masses):

\[
f_{mv} = \frac{c}{2\pi} \sqrt{\frac{\rho d}{(1/m_1 + 1/m_2)}}
\]

\[
R = 20 \log \left( \frac{m_1}{2m_2 + m_2} \right)
\]

\[
f_{mv} = \frac{c}{4\pi} \sqrt{\frac{(1,21/50*10^-3)(1/13+1/8)}{21}} = 120Hz\ (x 21 = 2520Hz)
\]

When calculated with a Noise prediction program it can be seen that the total Rw value is 33dB (see ANNEX).
#75 Predicted sound performance

**U VALUE**

<table>
<thead>
<tr>
<th></th>
<th>Thickness (m)</th>
<th>Lambda (W/mK)</th>
<th>$R_{tot}$ (K-W)</th>
<th>U-value (W/m²K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wall</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>air to FRP</td>
<td>1</td>
<td>50</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>FRP/epoxy</td>
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<td>0.18</td>
<td>0.02</td>
<td></td>
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<tr>
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<td>0.039</td>
<td>1.54</td>
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<td>FRP</td>
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<td>0.18</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Promasound</td>
<td>0.004</td>
<td>0.021</td>
<td>0.19</td>
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<tr>
<td>Batts 45</td>
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<td>0.04</td>
<td>1.25</td>
<td></td>
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<tr>
<td>FRP</td>
<td>0.008</td>
<td>0.18</td>
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</tr>
<tr>
<td>FRP to air</td>
<td>1</td>
<td>10</td>
<td>0.10</td>
<td></td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td></td>
<td>3.19</td>
<td>0.31</td>
</tr>
</tbody>
</table>

#76 Thermal U-value
Formulas that describes the dB for each frequency is as following:

\[
\frac{1}{t} = \left( \frac{(\omega_1 + \omega_2)^2}{2m_1m_2} \right)^2 + \left( \frac{n(\omega_1 + \omega_2)\omega_1\omega_2}{p\epsilon} \right)^2 \left( \frac{1}{f_{ls}} \right)^2
\]

\[R = 10 \log \left( \frac{1}{t} \right)\]

Sound proofing (Ga) of the partitioning structure:

\[Ga = Ra + 10 \log \left( \frac{V}{6*T0 * S} \right) -3\]

- \[Ra = \text{sound insulation in dB}\]
- \[V = \text{Volume of the room in m3}\]
- \[S = \text{area of the external partition structure in m2}\]
- \[T0 = \text{reference reverberation time in s (=0,8 for offices/cabins)}\]

\[-3 = \text{a constant term that is used to calculate the difference between the sound striking in practice and theory}\]

\[Ga (cabin)= 43 (33+10) + 10 \log \left( \frac{19,2/6*0,8 * 4,8}{6} \right) -3 = 41\text{dB(A)}\]

Sound level in a cabin is 85db(A) - 41dB(A) = 44dB(A).

Because it is very complicated to predict the behaviour of the sound mat it is assumed that the total mass (+promasound) will perform better than as with the outcome of the mass spring resonance formula. As described before the test of promasound is around 10dB higher then according the mass law. The graph of the total mass is shifted 1/3 of 10dB higher (#75).

It can be noted that the drop down takes place near a frequency of 100Hz. This is not ideal due to the helicopter noise. Increasing the mass (that is not preferred) or increasing the cavity width will move the drop down to the lower frequencies. When filling the cavity with sound insulation the weight will increase minimally but the drop downs will be less critical.

**Laboratory Sound test**

Due to the fact that prediction of the sound reduction of a layered sandwich element is complicated, a sound test should be performed. The combination of the specific materials used in the sandwich can give better results. The prototype panel will be made so it is flexible in its combination. The sound mat and sound insulation can be changed or even taken out, so different tests can be executed.

### 7.2 THERMAL U VALUE

According to the rules the total insulation will have a U-value not exceeding 0.50 W/(m²K).

Calculation (#76):

\[R = \frac{1}{\alpha} \]

\[R = \frac{\text{thickness}}{\lambda} \]

\[U = \frac{1}{R_{tot}} \]

\[U_{tot} = 0.31 (<0.5, \text{Correct}) \]

The panel possesses good thermal properties and can maintain or even increase the energy efficiency of the LQ.

### 7.3 FIRE PERFORMANCE

Plastics are normally not used in high risk fire environments. To solve this additives and fillers can be mixed in the resin.

When plastics are burning there can be an emission of heavy toxic smoke. To prevent this special attention must take place to the material composition.

The fire behaviour of glass fibre reinforced plastics is non-combustible for a long term. The disadvantage is that it is not known if the strength diminished, according to the rules. To prevent smoke a polyester skin and phenol foam will be good. However test should be done to be sure that the strength can be guaranteed during fire.

In skin

- additives (phenol, high costs) in the polyester resin
- Masterworks (polyproducts)
- Calcium mixed into resin with glass fibre (cheap and fire-resistant)

In core

- Calcium silicate, Skamotec 300 (incl. certificate)
- Cork
- Balsa

In between (glue)

- skamol super glue
- reversible glue
- Glue is not always necessary, depends on the materials being used.

Fillers:
#77 Production method
• aluminium tri hydraat, for a fireresistant resin and low smoke
• silicon carbides (SiC), expensive

Additives:
• DMMP, fire retardant with phosphor. It lowers the viscosity, and is used in polyester resins.

By adding other substances mechanical properties change, like the tensile strength weakens. Resins that are fire retardant by there composition are bisphenol polyester, bisphenol vinylester and epoxy (all novalac types). Besides these phenol and BMI are the most common for fire resistant applications.

High fire resistant resins:
• phenol (max. 150-230 ºC)
• special epoxy systems (phenol novalac max. 230 ºC)
• BMI resins (>230ºC, better mechanical properties than epoxy for higher temperatures)
• Polyimide resins (PMR15 >315 ºC)

Advantages of phenol resins in case of fire:
• no automatic development of fire
• very low emission of smoke
• low emission of toxic gasses
• low heat release
• no flammable fumes
• keeps mechanical properties under temperatures of 200 ºC

Masterworks is already used as coating for mine shafts. It is a water-based resin with acrylic polymers, gypsum and mineral fillings which can be combined in liquid condition. For Masterworks it is proofed with several tests that it can be used in housing according to European norms.

Production
Ideal is to have a continuous production process. This will be possible by the pressing mould technique or spray technique (##77). Hand lay-up is to slow in process. Production for one panel is about two hours. For this stage the injection technique will be used.
#78 Final geometry

#79 Longitudinal assemblage

#80 Wall panel types
8. FINAL DESIGN

In this chapter the final design will be described. The focus will be on the functionality, skeleton, the panel and the assemblage method. After this the prototype will be discussed. At last the costs and total weight will be described.

8.1 DESIGN

Funcionally
After the research a new concept is developed: the smart module. The idea is to chop the existing LQ layout, creating smaller modules. The dimensions are 10m length, 4m width, 3.5m height. The modules can be easily places aside or on top of eachother having a type A module and type B module. Side panels and roof panel will be installed when all modules are in place. (#78).

Skeleton
The skeleton will exist of extruded aluminium profiles. The specific weight, a clean material and flexibilty in shape are the main reasons to shift from steel to an aluminium alloy. In the previous chapter it is proven that the maximum defermation and stresses are within the limits for all scenarios (transport, lifting, in place). Bracing will be used when necessary.

Panel
The panel exist of a structural part:
FRP-A60 insulation-FRP

Sound/blast part:
Soundmat-cavity (filled with acoustic insulation-FRP)

Panel dimensions are 4000mm width x 3500mm height.
Total thickness is 126mm.

Two types of wall panels are introduced, type A and B. Floor panels are already integrated in the design. Roof panel will be fixed afterwards when all modules are stacked on top of eachother (max 4 height). (#79, #80)

Assemblage
The assemblage of the panel will be executed by a clamp system. Minimal tolerances are needed and welding and bolting are eliminated (clean construction methode).

8.2 PROTOTYPE

To introduce FRP in the offshore market a prototype is desirable, even necessary to proof the design will fulfil all the technical performances and meet the stringent offshore rules. Because of a limited budget the design will be as close to the design as possible. At first the prototype is made to have an idea of the final weight and to see and feel the materials. Are the expectations coming truth. Secondly the production method will be explored. What are the obstacles in the manufacturing process, what should be changed or could be done better. Thirdly the assemblage of the panel into the structural should be proven. Is the clamp system working, what about tolerances and reliability. At last the prototype can be used for testing.

Before starting the production a prototype design has been made together with a material take off (ANNEX).

Skeleton
The aluminium frame will have a dimension of 1500mm (height) x 500mm width supported by an aluminium standard.

To approach the skeleton as close as possible a frame will be made with the aluminium shs100x100x4 as in the design. An extrusion profile is not possible in this stage because an expensive mould should be specially made for the designed profile. Two alternatives where possible to create a similar profile.

First one needs cutting out of parts in the aluminium tube and replacement of clamp profiles made by the milling machine. The clamp profiles consist of several layers bolted on top of each other. This should give the most similar idea of the clamp. However milling of these clamps (total 6 pieces) and extra material needed was time consuming and costly. Also welding is necessary to insert the clamps in place. After producing two clamps there is chosen for the other alternative. In this second option holes will be cut out in the profile itself functioning already as part of the clamp. In this way less material is needed and welding is excluded. Only the
#81 End profiles

#82 Profile milling

#83 Integrated clamp

#84 Aluminium standard
slide-profile has to be made separately together with the hold-back profile that will be bolted on the panel (#81, #82, #83, #84)

**Panel**
The panel will have a dimension of 1500mm (height) x 500mm inside / 750mm outside with a thickness of 126mm. The sandwich is constructed of the following layers:

**outer skin:**
- glass fibre mat + sorex + glass fibre mat + sorex + glass fibre mat filled with epoxy
- insulation / air gap
- Promasound bolted on the in-between skin

**in-between skin:**
- glass fibre mat + aluminium plates + glass fibre mat filled with epoxy
- insulation A60 rated

**inner skin:**
- glass fibre mat + sorex + glassfibre mat filled with epoxy
- profiles made of wood to close both sides of the panel keeping the layers together.

**Production**
For the production of the glass fibre panels the method of vacuum injection moulding is used. Before starting this process a mould is necessary. The mould is made of a hardcore (concrete) panel with wooden boards glued on top. The mould could be used for both inner and outer skin. The in-between skin is made on an aluminium plate. Difference between the two methods is that the first one needs double vacuum, because direct lamination on the mould is not possible. Lamination will be executed in a kind of plastic bag (on both sides plastic foil). This to prevent that the plate will be fixed to the mould. For the other method the aluminium plate has been polished several times so direct lamination is possible and the plate will loosen easily. To produce the outer skin the following layers are needed (from bottom to top):
1. the mould
2. a plastic foil with a tube connected to the vacuum pump
3. glass fibre mat
4. sorex
5. glass fibre mat
6. sorex
7. glass fibre mat
8. foil that will loosen from the previous layers (will not bond with epoxy)
9. net, for equal distribution of the epoxy resin
10. open tube over the net to distribute the epoxy resin
11. open tubes along the panel to draw off left over epoxy by suction (connected to vacuum pump)
12. a plastic foil with a tube connected to the vacuum pump

Because there is a 90° angle in the panel it is chosen to do the vacuum injection in two steps. First step includes only one glass fibre mat to guarantee the right angle. After hardening the other layers will be laid on top in the second step. The inner and in-between skin are made in a similar way. After hardening of all the panels the layers that will not bond with the epoxy are pulled off. The left over panel can be taken of and is cut on size by a hand saw tool.

Insulation standard sizes are 600mm x 1000mm. The specific shape of the panel is made by the sawing machine, and to reach up to 1500mm the insulation panels are connected by male-female. To ensure the stiffness of the structural panel the inner and in-between skin are glued on both sides of the A60 insulation by an epoxy hardener. Other layers will be bolted together so testing is possible in different layer combinations (#85).
Production panel with vacuum injection technique
8.3 COST
It is complicated to say something about the costs in this stage of development. The construction, assemblage and production method are subjected to the strong technical developments.

The main cost nowadays are as following:
Structural + blasting & coating = 25 %
Arch. & Furniture = 30 %
HVAC = 10 %
Piping = 5 %
E&I = 12.5 %
Loss control = 2.5 %
Project Management & Engineering = 15 %

It can be noted that engineering costs and blasting and coating will be reduced due to the use of FRP and the new (repeating) smart module production. Also the life cycle time will be expanded due to the flexibility.

8.4 WEIGHT
The weight reduction for the skeleton will be around 25 percent. With a prototype of a wall panel the weight reduction per m2 compared with the construction nowadays is around 35 percent. However functional requirements as sound reduction and fire resistance need to be tested and certified before use. For architectural items main reduction in weight can be found in the flooring, wall and ceiling panels and furniture. Overall 40 percent in weight can be saved.

Total weight saving:
Structural 30% of 50% = 15%
Architectural 40% of 20% = 8%

*The overall weight saving will be around 23% for both structural and architectural on the total weight.*

Advantages can be found in assemblage, maintenance, longer life-cycle, flexibility (change of POB), durability, performance, and transport fuel (less CO2).
9. CONCLUSIONS

At first the new elements that are proposed will be summed up. From all the study described in the previous chapters conclusions will be derived. After this recommendations will be given how to follow up and improve the design.

9.1 NEW ELEMENTS
• Introducing new materials: Aluminium, FRP, Sound Mat
• Concept ‘Smart Modules’, flexible design
• Clamp assemblage
• Extrusion Profile
• (High performance) Sandwich Panel

9.2 CONCLUSIONS (LESSONS LEARNT)
• The panel possesses good thermal properties and will increase the energy efficiency of the LQ.
• Reduced maintenance and longer life time (>30 years)
• Reduced transportation and installation costs
• Specific resin and coating systems will improve the fire performance. The specific composition of the sandwich can improve this by a multilayered system. However a real Fire test should be performed.
• Acoustic performance is predicted to be good by introducing a layered sandwich and a sound mat
• Easy installation of the panels by a clamp system. This is a simple and clean proces. The panel could be made in other variants so welding or bolting is possible.
• The panels can exhibit a number of textured surface finishes.
• The surface skin resist impact and stain, dirt is easy to clean. No painting costs.
• For explosion a thermoplast external skin is preferred.
• Engineering cost will be minimized due to a repeating production
• The overall weight saving will be around 23% for both structural and architectural on the total weight.

9.3 RECOMMENDATIONS
• Panels should be made in a continuous manufacturing (pressing) process to reduce the costs.
• By using thermoplasts in the future panels are recyclable.
• Fire, sound and strength test should be performed
• research for lighter core material with high performances
• delamination research (glue or stitching)
• further development of the clamp (testing) and aluminium (extruded) profile
• building a 1:1 smart module
• continue with scenario 2 and 3......
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6. Solico, solution in composites
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Lab
1. Inholland Composiet Lab

Associations
1. TPRC (ThermoPlastic Composite Research Centre)
2. VKCN (Vereniging Kunststof Composieten Nederland)

Internet:
13. SPS inteligent engineering ???
ANNEX I

DIANA SCRIPT

FEMGEN MODEL : Basis
ANALYSIS TYPE : Structural 3D

'UNITS'
MASS KG
LENGTH M
TIME SEC
TEMPER KELVIN

'COORDINATES'
1 0.000000E+00 0.000000E+00 0.000000E+00
2 0.000000E+00 0.000000E+00 1.750000E+00
3 0.000000E+00 0.000000E+00 3.500000E+00
4 0.000000E+00 0.000000E+00 5.250000E+00
5 0.000000E+00 0.000000E+00 7.000000E+00
6 0.000000E+00 0.000000E+00 8.750000E+00
7 0.000000E+00 0.000000E+00 1.050000E+01
8 0.000000E+00 0.000000E+00 1.225000E+01
9 0.000000E+00 0.000000E+00 1.400000E+01
10 0.000000E+00 0.000000E+00 1.575000E+01
11 0.000000E+00 0.000000E+00 1.750000E+01
12 0.000000E+00 0.000000E+00 1.925000E+01
13 0.000000E+00 0.000000E+00 2.100000E+01
14 0.000000E+00 0.000000E+00 2.275000E+01

-----------------------
769 CQ40L 1701 1862 1702 1872 1711 1881 1710 1871
770 CQ40L 1702 1863 1703 1864 1882 1711 1872
771 CQ40L 1432 1873 1703 1883 360 359 202 1621
772 CQ40L 1703 1874 1704 1884 362 361 360 1883
773 CQ40L 1704 1875 1705 1885 363 362 361 1884
774 CQ40L 1705 1876 1706 1886 366 365 364 1885
775 CQ40L 1706 1877 1707 1887 368 367 366 1886
776 CQ40L 1707 1878 1708 1888 370 369 368 1887
777 CQ40L 1708 1879 1709 1889 372 371 370 1888
778 CQ40L 1709 1880 1710 1890 374 373 372 1889
779 CQ40L 1710 1881 1711 1891 376 375 374 1890
780 CQ40L 1711 1882 143 142 141 377 376 1891

MATERIALS
/281-780 / layers 2 5 2
/ 1-280 / 4
GEOMETRY
/281-780 / 4
/ 1-120 161-280 / 8
/ 121-160 / 11
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1 YOUNG 2.100000E+05
POISON 3.000000E-01

DENSIT 7.800000E-06
2 YOUNG 1.600000E+04
POISON 1.000000E-01
DENSIT 2.000000E-06
3 DENSIT 2.500000E-07
4 YOUNG 7.000000E+04
POISON 3.400000E-01
DENSIT 2.700000E-06
5 YOUNG 3.000000E+01
POISON 1.000000E-01
DENSIT 1.000000E-07

'GEOMETRY'
1 PROFIL IPEA 140
2 PROFIL IPEA 300
3 PROFIL HEA 100
4 THICK 1.080000E+02

LAYER 3.700000E-02 9.259999E-01 3.700000E-02
5 BOX 8.000000E+01 8.000000E+01 3.000000E+00
3.000000E+00 3.000000E+00 3.000000E+00
6 BOX 1.400000E+02 1.400000E+02 3.000000E+00
3.000000E+00 3.000000E+00 3.000000E+00
7 BOX 3.000000E+02 3.000000E+02 3.000000E+00
3.000000E+00 3.000000E+00 3.000000E+00
8 BOX 1.000000E+02 1.000000E+02 4.000000E+00
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9 BOX 2.000000E+02 2.000000E+02 3.000000E+00
3.000000E+00 3.000000E+00 3.000000E+00
10 BOX 1.500000E+02 1.000000E+02 5.000000E+00
5.000000E+00 5.000000E+00 5.000000E+00
11 RECTAN 4.000000E+00 5.000000E+01

'GROUPS'

ELEMEN
1 COLUMNS /1-10 21-30 41-50 61-70 81-120 /

NODES
2 COLUMNS_N /1-21 41-61 81-101 121-141 161-244 /

ELEMEN
3 FLGIRDER /31-40 71-80 /

NODES
4 FLGIRDER_N /1 61-80 101 141-160 /

ELEMEN
5 RORING /211-270 /

NODES
6 RORING_N /21 41 81 101 121-141 161-244 /

ELEMEN
7 RFGIRDER /31-40 71-80 /

NODES
8 RFGIRDER_N /21 41 81 101 121-141 /

9 DAMPERS /1 61 101 141 /

ELEMEN
10 FLRING / 161-210 271-280 /

NODES
11 FLRING_N / 1 61 101 141 181 202 223 244 321-415 530-548 /
ELEMEN
FORCE -0.300000E+01
DIRECT 3

12 BRACING / 121-160 /

NODES
13 BRACING_N / 1 61 101 141 181 202 223 244 321-415 /
ELEMEN
FORCE -0.300000E+01
DIRECT 3

14 SANDWICH / 1-80 161-210 271-780 /

NODES
15 SANDWICH_N / 1-160 181 202 223 244 321-415 530-548 /
ELEMEN
FORCE -0.300000E+01
DIRECT 3

16 RFRING / 31-40 71-80 161-210 271-280 481-780 /

NODES
17 RFRING_N / 1 61-80 101 141-160 181 202 223 244 321-415 530-548 1071-1891 /
ELEMEN
FORCE -0.300000E+01
DIRECT 3

FLOOR / 31-40 71-80 161-210 271-280 481-780 /

NODES
19 FLOOR_N / 1 61-80 101 141-160 181 202 223 244 321-415 530-548 1071-1891 /
ELEMEN
FORCE -0.300000E+01
DIRECT 3

'SUPPORTS'
/ 1 61 101 141 / TR 1
/ 1 61 101 141 / TR 2
/ 1 61 101 141 / TR 3

'LOADS'
CASE 1
ELEMEN
/ 11-20 /
LINE
FORCE -0.300000E+01
DIRECT 3

/ 31-40 /
LINE
FORCE -0.300000E+01
DIRECT 3

/ 241-250 /
LINE
FORCE -0.300000E+01
DIRECT 3

/ 251-260 /
LINE
FORCE -0.300000E+01
DIRECT 3

/ 261-270 /
LINE
FORCE -0.300000E+01
DIRECT 3

CASE 2
WEIGHT 3 -9.81000

CASE 3
ELEMEN
/ 281-380 /
FACE
FORCE 0.125000E-02
DIRECT 2

'DIRECTIONS'
1 1.000000E+00 0.000000E+00 0.000000E+00
2 0.000000E+00 1.000000E+00 0.000000E+00
3 0.000000E+00 0.000000E+00 1.000000E+00

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## ANNEX II

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<th>Freq (Hz)</th>
<th>R (dB)</th>
<th>Freq (Hz)</th>
<th>R (dB)</th>
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<td>Freq (Hz)</td>
<td>R (dB)</td>
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**ANNEX III**

**MEETINGS CHRONOLOGICAL**

Fred Veer 30-09-2009

Probleem:
Er ontstaat een vraag naar lichtgewicht modules voor de offshore.

Notities:
- moet de container stapelbaar zijn? -> ja
- referentie KIP caravan
- gewichtsbesparing hoogstens 15-30%
- let op knik en stijfheid
- lichtmetaal HSLA, DOMEX/DOPEL! (SSAB)
- gebruik CES, low alloys, level 3
- Domex is heel taai
- 4mm composiet is zwaarder dan 1mm staal
- Als tegenhanger van de gebruikelijke staal constructie bestaan aluminium containers. (Scandinavië) Het nagenoeg exclusieve gebruik van waterkracht stelt Noorwegen in staat zijn installaties economischer en schoner te gebruiken dan de meeste andere landen.
- Gebruik koud gezette profielen
- vraagstuk is actueel, echter gericht onderzoek blijft uit
- Let op vermoeingsgedrag
- Modelleren in DIANA, moeilijkheid zit in de verbindingen en koppelingen
- BOUT heeft een nieuwe dvd Ashby voor vergelijk gewichtsbesparing en kosten
- Dit onderzoek vraagt veel kennis en ervaring, 20 man!?  

Conclusie:
Het materiaal composiet zal een lichter materiaal zijn dan staal. Echter, lettend op de offshore omstandigheden (hijsen->beschadiging) zal composiet lastig te repareren zijn. Als constructie zal deze zo samengesteld moeten worden, dat de uiteindelijke gewichtsbesparing minimaal is. Bovendien zal er een geheel nieuw productieproces ontwikkeld moeten worden met zich meebrengend de omscholing van het personeel. Dit zal kosten met zich meebrengen. Om deze te beperken zou gezocht moeten worden naar een ander materiaal die een soortgelijk productieproces heeft als de huidige. (lichtmetalen)

Vraag:
Gezocht moet worden naar een lichtmetaal skelet (die de sterkte en hijsvermogen garanderen), Domex, waarbij de vloerplaten en het wandsysteem gemaakt zijn van een samengesteld materiaal (composiet).

Everstrip 01-10-2009

- bedrijf bestaat 1,5 jaar
- relatief klein bedrijf
- verleden in jachtbouw en sandwichpanelen
- problematiek: mal en delaminatie
- Everstrip moet nog berekend worden, wordt nu gedaan in ComposietLab InHolland
- Door een verstijvingschot wordt de samendrukbaarheid belemmerd
- EKON.nl
Ontwikkeling in zwembadvloeren en laadvloer vrachtschepen
- Glasvezel polyester
- Basalt (gesteente) vezels, hoe te verbinden
- Profiel is 2,5 meter breed, 5kg/m
- Kevlar? (is de door DuPont gebruikte handelsnaam voor een aramidevezel)
- Project, er is een grote subsidie pot -> Alliantie groot Composiet
- Staalskelet is niet nodig
- Doel 1+1=3. 1 Materiaal met alle eigenschappen in zich!!!!
- Over 2 weken is er meer info (testresultaten van InHolland)
- GRP leidingen zijn ook brandwerend!
- PRIJS? PRODUCTIEPROCES?

Samenwerkingverband mogelijk:
TU Delft - InHolland – Hertel - Everstrip

Michiel Hagenbeek (InHolland Composiet lab)
13-10-2009
- aanname 50GP in stijheid
- glasvezel alleen op trek belasten (beton op druk)
- probleem is niet de mogelijkheid maar het vaststellen van harde eisen
- waarschijnlijke keuze: glasvezel-epoxy (waarom??) met een injectietechniek
- referentie: cargoshell van polyproducts
- slimme verbindingen (male –female) voor schuifkrachten

Harde eisen (getallen)bepalen tov:
- hoeveelheid? (reproductie of uniek)
- modulair!!
- Brandeis (A60)
- Gewichtwinst (50%)
- Uv straling
- Levensduur
- Tensile Modulus
- Belastingen (vloer, dak, wind, green wave, liften)
- Geluid
- R-value (thermisch)
- Blast??
- Kosten
- (be)werkbaarheid
- schade
- penetraties?
- Productieproces

Drie varianten:
1) monocoque (Monocoque is samengesteld uit “mono” (het griekse woord voor enkel) en “coque” (het franse woord voor schaal). Het is een constructietechniek, waarbij de dragende constructie wordt gevormd door de schaal, ofwel de buitenhuid, zonder invendige versterkingen. Een ei is hiervan een goed voorbeeld uit de natuur. Een monocoque is licht en torsiestijf, echter de productie is zeer bewerkelijk. De belasting wordt hierbij opgenomen door de buitenhuid van een object, in tegenstelling tot constructies met een frame- of een vakwerkconstructie, die vervolgens wordt voorzien van een niet-dragende buitenhuid. Deze techniek werd in de jaren '30 voor het eerst toegepast in de vliegtuigindustrie. (Mal??)
2) Frame (koolstof composiet) en composiet panelen (voordeel: hetzelfde uitzettingscoefficient, een materiaal
3) Frame steel (Domex) en composiet panelen (gewichtsvoordeel?)

Airborne Composites
14-10-2009

Spreker: Wiard Leenders MSc  w.leenders@airborne.nl  070-3017400  06-21250003

Hoofdvraag:
Waarom is composiet zo bijzonder? Tov staal of aluminium
- streven naar 6 activiteiten (bijeenkomsten) per jaar
- vaste en vloeistof mechanica
- werkzaam op 2 locaties (Den Haag NL, Girona E)
- airborne ontwerpt en bouwt met composiet
- werkzaam in de high end technology
- projecten: antenna structures beattande uit composiet segmenten, structural panels voor in de ruimte. Moet dus
100% goed zijn (testen etc), onderdelen Fokker vliegtuig.
- defensie krijgt een hoge prioriteit
- niet voorceren naar composiet als staal goed werkt
- recyclebaar: thermoharders niet, thermoplast zou kunnen (paaltjes)
- eigenlijk een vervuilende industrie
- 1 antenne 10-15 ton vanwege onderstel dat nog steeds van staal gemaakt is
- Gulfstream
- 15 man engineering  (totaal 100 man incl. Spanje)

Enability properties:
- specific strengt
- specific stiffness
- mass
- chemical resistance
- CTE (coefficient for thermal expansion) value, Arctic Modules!
- Failure (geen vloei) geen waarschuwing (nadeel), kan er wel goed mee rekenen (voordeel)
- Tailoring material properties
- Freedom of shape
- Fire behaviour (veel rookontwikkeling, maar constructie blijft langer heel) Een langzame wardoorgang.

Vraagstuk: hoe top laag te beschermen)
- (integral) cost

Challenges:
- less weight
- faster
- stronger
- stiffer
- temp. Sensitivity (temp. Ongevoelig)
- redundancy
- lower cost
- geen uitzetting. INVAR werd een probleem dus werd gekozen voor composiet (voor ALMA telescopes)

Vergelijk met:
Isotroop materiaal
- steel
- aluminium
- titanium
- bronze
- ……………
An-isotroop
- wood
- ……………

Rondleiding
- Prepreg (vacuum verpakte composiet, vezels en hars, delen) komen aan in de vriezer
- Nergens aankomen, ruimte is op overdruk, pak aan
- Snijden gebeurd bijna allemaal machinaal
- Mal moet ook van composiet zijn vanwege uitzettingscoëfficiënt
- Plug -> mal -->product
- Geen naden door overlap te creëren
- Ook sandwiches! Alu Honingraat of schuim!
- UD = vezels in een richting
- Gaten kunnen gemaakt worden en achteraf worden de randen geplakt.
- Verstijvingschotten worden gebout, daarna met vezel mat in elkaar overgesmeerd. Bout kan achteraf weggehaald worden, maar wordt niet gedaan. Vliegtuigen worden totaal gelijmd.

Hertel Defence &Offshore MT
10-12-2009

Aanwezigen:
TD, GV, YR, GB, MW, KH, HS, PA, AB

MW: Drill Riggs, gewicht ook van belang
GB: desirable, safety!
PvA: eisen, geld? Kostprijs
TD: Historie probleem, hoe gedraagt het materiaal zich na een aantal jaren
TD: vezeloplossing, van te voren rekening houden: vezelvrije vlakken
HS: krijgen we een schoner werkplaats? Of niet……vezels?
GV: tip: weegfactor invoeren bij value assesment (belangrijkste boven?)
KH: productie kunststof lastig? Ref de Ruyter, Bonkot?
AB: we moeten dan een samenwerking aangaan met kunststof bedrijf
PA: overgaan naar een standaard (smart module) voor verhuur
TD: neem de discipline engineers mee in kunststof
MW: concentreer je op structural maar prikkel de engineers
PA: maar wat wil de klant?
MW: wat is het waarde voor de klant?
AB: is er restafval (aardolie) van de klant (Shell) dat kan worden gebruikt voor composiet?

Vervolg………..

Ab/MW staalskelet met comp panelen / Alu + comp panelen is onderhoudsvrij (A60?). Verbindingen?
GB: Scenario 3 is hoog inzetten
TD: we moeten de smart module aandurven met composiet monocoque
AB: onderhoud, life cycle costs (lcc)
GV: beter stap 1, eerst ervaring opdoen en kennis vergaren
AB: neem alu als vergelijk. Je moet meer voordelen halen dan gewicht bijv. energie-verbruik (alu_comp)
MW: optie 1: - 15-20% gewicht / +10-15% kosten

Lichter, onderhoudsvrij, prijs, productie, geld ook voor alu.
Misschien is het voordeel te halen in een standaard.

Polyproducts
20-04-2010

Albert ten Busschen
Brandcurve WBDBO
Thermisch is geen probleem
Waarom na WO2 opkomst kunststof
Baekeland ontwikkelde bakeliet rond 1900. Fenol, echter hier worden schadelijke zuren gebruikt tijdens het productie-proces.

Tijdens WO2 kwam de vraag voor schepen en de romp van een vliegtuig.
Neusvleugel moest voldoen aan:
- radiotransparant
- vormvrijheid
- sterkte
Composiet voldoet hier aan

Uitzetting kan 0 zijn echter alleen in vezelrichting.
Delta L=α x ΔT x L

Alpha glas = 10x10^-6
Alpha steel = 10x10^-6
Alpha alu = 24x10^-6
Alpha PE = 200x10^-6
Alpha glasmat = 24x10^-6
Alpha carbon l (longitudinal) = -0.5x10^-6
Alpha carbon t (transversaal) = 20x10^-6
Alpha aramide l = -4x10^-6
Alpha aramide t = 30x10^-6

Lage tonen (frequencies zij het probleem)
Voor acoustic kunnen cassettes gevuld worden met water,
Tijdens transport leeg, in gebruik vullen met water (vriezen?)