GTT Membrane Cargo Containment Systems
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Agenda

- Introduction to GTT
- Introduction to Membrane tanks
- MkIII Concept
- NO96 Concept
GTT in brief

▶ An engineering company with more than 50 years of experience in the design of the Membrane Cargo Containment Systems

▶ GTT is a public company listed on the Euronext Stock Exchange (Paris)

▶ More than 130 projects\(^1\) (LNGCs, FSRUs, FLNGs, GSTs and “LNG as a fuel”) currently on order

▶ 380 highly qualified people\(^1\) keeping on addressing new market requirements, such as:
  ▶ **Low BOR systems** (particularly for spot)
  ▶ **Intermediate filling levels** (particularly for offshore)
  ▶ **Small scale LNGCs** (for retail LNG)
  ▶ **LNG as a fuel tanks** (for bunkering)
  ▶ **Multigas vessels**

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\(^1\) As of December 31\(^{\text{st}}\), 2014
GTT History

Technigaz MkI System

• 1964: Pythagore : 630 m3 (2 tanks)
• Converted fish carrier

Figure 3: Pythagore LNG carrier; general overview and inside tank view
GTT History

Gaztransport NO System

1969: Polar Alaska : 71,500 (4 tanks – NO82)
GTT History

Gaztransport

Technigaz

1994 - GTT

NO96

MkIII
Group and Organisation

GTT Group

GTT North America Subsidiary

Cryovision Subsidiary

GTT Training Subsidiary
#### GTT’s Contribution

**Pre-Design**
- Assistance to Shipowners, Shipyards and Engineering Companies for feasibility and optimization before contract
- Bill of materials, Equipment pre-sizing...

**Design**
- After contract, detailed engineering for Cargo Containment System (CCS) and Cargo Handling System (CHS)
- Material specification & homologation

**Construction**
- On-site supervision during construction
- Attendance to gas trials & commissioning

**Operations**
- Assistance and expert advice during operations

**Maintenance**
- Assistance and expert advice during ship life
Building Shipyards

Technical Assistance and License Agreement
- Non exclusive in terms of geography
- Non exclusive in terms of technology
- Access to new patents
- Identical terms for all Licensee
- Identical pricing whatever the technology, the country

Presence on-site
- Permanent office in shipyards

Joint research programmes
- Constantly working on common goals

26 shipbuilding groups\(^{(1)}\) are GTT partners for the construction of membrane LNG carriers

\(^{(1)}\) As of June 2014
Ship Owners

- **Technical Services Agreement**
  - Advisory service for the maintenance and operation of the LNG fleet
  - Round the clock service on-site
  - Training
  - Engineering studies upon specific request
  - Assistance with statutory bodies

(1) As of May 2014
Repair Shipyards & Repair Service Providers

- **Technical Assistance for the Maintenance of Membrane LNG Carriers**
  - Training
  - Advisory service for the preparation of each maintenance operation
  - Round the clock service

- **16 repair shipyards and 2 repair services providers\(^{(1)}\) under contract on the world shipping routes**
  - Europe (France, Germany, Italy, Portugal, Spain)
  - Middle East (Dubai, Qatar)
  - Asia (China, Japan, Malaysia, Singapore)

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\(^{(1)}\) As of May 2014
GTT Technology Applications

LNG Carriers

As of May 2014
GTT Technology Applications

Floating Storage & Regasification Vessels (FSRV)
GTT Technology Applications

Floating Production Storage and Unloading (FLNG)

**Dimensions**
- 488m long
- 74m wide
- 600,000 tns ballasted
- 3.6mtpa of LNG
- 1.3mtpa of condensate
- 0.4mtpa of LPG

**Storage**
- 220,000m³ LNG
- 90,000m³ LPG
- 126,000m³ condensate
GTT Technology Applications

Land Storage Tanks
GTT Technology Applications

LNG as a Fuel – Bunker Barges

North America’s first LNG bunker barge
GTT Technology Applications

LNG as a Fuel – Vessel Fuel Tanks
Introduction to Membrane Tanks
Objective

• Regulatory requirements
• Design philosophy of Membrane systems
• Ship Design
• Liquid Motion
Regulations for Gas Carriers


Enforced through SOLAS Chapter VII – Carriage of Dangerous Goods
Tank Types for LNG

IGC Code
Tank Classification

Independent Tanks

Type A
Pr < 700mb
Full Secondary Barrier

Type B
Pr < 700mb*
Partial Secondary Barrier

Type C
Pr > 2 bar
No Secondary Barrier

Membrane Tanks

Membrane
Pr < 700mb
Full Secondary Barrier

NO 96

Mk III

*For tanks with plane surfaces
NO96 & MkIII Technologies

NO96 Cargo Tank

MkIII Cargo Tank
Membrane Containment System
Basic Concept

- Inner Hull
- Insulated lining
- Hull structure
“Membrane tanks are non-self-supporting tanks which consist of a thin layer (membrane) supported through insulation by the adjacent hull structure. The membrane is designed in such a way that thermal and other expansion or contraction is compensated for without undue stressing of the membrane.”

- The membrane and hull behavior are intimately linked.
- The containment transmit the load whereas the hull takes the load
- The membrane should be flexible (thin) and/or should be suitable for cryogenic use (low contraction coefficient)
- The membrane should be flexible to absorb hull deformation
Membrane & Hull Intimately Linked

- Protect the hull structure from the low temperature
- Transfer the loads to the hull structure
- No loss of space, cargo volume maximized
- Accommodate any kind of hull form and size
- Large volumes
IGC 4.2.2.2 Membrane Tank Philosophy

“The design vapour pressure $P_o$ should not normally exceed 0.25 bar. If, however, the hull scantlings are increased accordingly and consideration is given, where appropriate, to the strength of the supporting insulation, $P_o$ may be increased to a higher value but less than 0.7 bar.”
IGC 4.3 Design Loads

4.3.1.1
Tanks together with their supports and other fixtures should be designed taking into account proper combinations of the following loads:

- Internal pressure
- External pressure
- Dynamic loads due to motions of the ship
- Thermal loads
- Sloshing loads
- Loads corresponding to ship deflection
- Tank and cargo weight with the corresponding reactions in way of supports
- Insulation weight
- Loads in way of towers and other attachments
Ship Deflections - Global

Hull Girder Deflection

**Hogging**
- Higher weight at ends
- Higher buoyancy in the middle part

**Sagging**
- Higher buoyancy at the ends
- Higher weight in the middle part
Ship Deflections – Local Ballast Pressure

Max ballast pressure ~ 4 bars
IGC 4.7.3 Secondary Barrier Requirement

Secondary barriers in relation to tank types should normally be provided in accordance with the following table.

<table>
<thead>
<tr>
<th>Cargo temperature at atmospheric pressure</th>
<th>-10°C and above</th>
<th>Below -10°C down to -55°C</th>
<th>Below -55°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic tank type</td>
<td>No secondary barrier required</td>
<td>Hull may act as secondary barrier</td>
<td>Separate secondary barrier where required</td>
</tr>
<tr>
<td>Integral</td>
<td></td>
<td></td>
<td>Tank type not normally allowed¹</td>
</tr>
<tr>
<td>Membrane</td>
<td></td>
<td>Complete secondary barrier</td>
<td></td>
</tr>
<tr>
<td>Semi-membrane</td>
<td></td>
<td>Complete secondary barrier²</td>
<td></td>
</tr>
<tr>
<td>Independent</td>
<td></td>
<td>Complete secondary barrier</td>
<td></td>
</tr>
<tr>
<td>Type A</td>
<td></td>
<td>Partial secondary barrier</td>
<td></td>
</tr>
<tr>
<td>Type B</td>
<td></td>
<td>No secondary barrier required</td>
<td></td>
</tr>
<tr>
<td>Internal Insulation</td>
<td></td>
<td>Complete secondary barrier</td>
<td></td>
</tr>
<tr>
<td>Type 1</td>
<td></td>
<td>Complete secondary barrier is incorporated</td>
<td></td>
</tr>
<tr>
<td>Type 2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4.7.4 Secondary Barrier

The secondary barrier should be so designed that:

.1 it is capable of containing any envisaged leakage of the liquid cargo for a period of 15 days, unless different requirements apply for particular voyages, taking into account the load spectrum referred to in 4.3.4.4;

.2 it will prevent lowering of the temperature of the ship structure to an unsafe level in the case of leakage of the primary barrier as indicated in 4.8.2
Cofferdams

Cargo Tanks

Cofferdams
Ship Design Requirements
Objectives

▶ Basic design principles
▶ Reinforcement requirements
▶ Propulsion & reduced Boil Off Rate
▶ Thermal analysis
▶ Cofferdam heating
Membrane LNGC design rules: Tank layout

- Cargo capacity < 180,000 M³: 3 + 1 Tanks
- Cargo capacity > 200,000 M³: 4 + 1 Tanks
Design rules: geometrical requirements

Transverse section:

- Upper chamfer $\geq 30\%H$
- Lower chamfer $\geq 2.50m.$
- Angle of chamfer $\approx 135^\circ$
Reinforcement distribution

Adjusted to operational profile

Go through sloshing analysis for non conventional applications

- Evaluate the max. expected impact pressures
- Compare with the CCS strength and behavior

Large cargo capacity

Offshore loading or unloading
Reinforcement Distribution, Example for NO96
BOR & Propulsion Systems

BOR = 0.150\%p.d. 

BOR = 0.100\%p.d.
Protecting the Inner Hull

- **Outer hull under IGC code requirement**
  - $T_{air} = 5^\circ \text{C}$,
  - no wind,
  - $T_{sw} = 0^\circ \text{C}$
  - Primary barrier damaged

- **Inner hull under USCG requirement**
  - $T_{air} = -18^\circ \text{C}$,
  - Wind speed = 5 Knots,
  - $T_{sw} = 0^\circ \text{C}$
  - Air inside cofferdam at $5^\circ \text{C}$
  - Primary barrier damaged
Cofferdam heating system

• Cofferdam heating system allow a temperature of +5°C inside cofferdam in damaged conditions, to comply with grade A steel.

• Fully redundant as per IGC Code (§ 4.8.4)

• It includes:
  ▪ 2 redundant coils per cofferdam
  ▪ Glycol water mixture
  ▪ 2 equally sized heaters (steam heated, shell & tube type)
  ▪ 1 expansion tank
  ▪ 1 glycol storage tank
  ▪ 1 water/glycol mixing tank

• 1 electric heater recommended (and designed) for normal conditions
Liquid Motion
Objectives

▶ What is sloshing?
▶ Calculating sloshing loads
▶ Reducing effects of sloshing
Sloshing – What is it?

High fillings: standing wave impacts located on tank discontinuities, i.e. bottom of upper chamfers and ceiling.

Low fillings: progressive wave impacts located on lower chamfers and longitudinal walls.
The effects of sloshing in tanks

- **EFFECTS OF SLOSHING**
  - On Pump Tower structure: *Drag force*
  - On Cargo Containment System: *Impact Pressure*

Pump Tower
Sloshing: Global and Local

Sloshing: global behaviour...
- Sea-waves & ship motions
- Tank geometry & filling level
- Change of momentum of the liquid avoiding obstacles

... and local behaviour
- Escape of the gas
- Compression of gas
- Condensation
- Shock waves
- Fluid / structure interaction

Local effects induce high variability of loads

Courtesy of Sloshel consortium
Examples of impacts
Cause of sloshing

Waves

Ship motions

Cargo motions

Hull Girder loads
Parametric rolling

Sloshing Impact Loads

Particular Phenomenon deriving from a Complex Reality
How to estimate sloshing loads?

- Several options
  - Use full scale loads and feedback at sea
    - Difficult because of low occurrence number
    - Restricts innovative designs
  - Numerical simulation
    - Difficult as global and local effects cannot be considered simultaneously due to CPU constraints
  - Model tests
    - The best compromise but induce **scaling issues**

only **MODEL TESTS** considered relevant for CCS design against sloshing impacts
Tools to calculate loads

- DIODORE: Sea keeping
- Ship motions: 6 d.o.f. time series
- DIVA 3 D: Numerical simulation
  - Loads on pump tower
- HEXAPOD TEST RIG: 1/40 model tests
  - Impact pressures
Model testing: Impact pressures on CCS

6 d.o.f. test rig, fully automated (3 different rigs)

Model tank at scale up to 1/25

Independent measurement system: trajectory checking

Independent actuators: high precision of motions

Up to 300 sensors completely synchronized, dispatched in “array of sensors”

Tests with the same density ratio at full and model scales

Large range of motions can be simulated

Pressures for CCS sloshing assessment
Means to reduce sloshing

1. **Tank design**

2. **CCS design**

3. **Operational limits**
MkIII System Components
Objectives

- Mark III design concept
- System description
- Mark III Flex
- Mark V
MkIII Tank
Mark III Design Concept

The corrugated stainless steel primary barrier:

- Standard pitch: 340mm
- Thickness: 1.2mm
- Material: Stainless Steel 304L
Mark III design concept

The insulation panel components are made out of:

- **Secondary barrier: composite material**
  - Material: aluminum foil bonded between two glass clothes
  - Versions: flexible band (named ‘Flexible Secondary Barrier’ or ‘FSB’) or rigid foil (named ‘Rigid Secondary Barrier’ or ‘RSB’)

- **Insulating material:**
  - reinforced polyurethane foam ("R-PUF")
Mark III Design Concept

The insulation panel

- it is a prefabricated component integrating the two insulation layers and the secondary barrier and on top of which the primary barrier is welded.

![Typical "insulation panel"

- Secondary barrier
- Metallic component onto which the primary barrier is welded
- Insulation layer

Typical "insulation panel"
Mark III design concept

- Thickness of the insulation
  - Dedicated part for Mark III Flex at the end of the presentation

**MARK III**

270mm
Mark III design concept

- The Mark III components are:
  - highly standardized: low number of part references
  - highly prefabricated in workshop: ready-to-use

- The Mark III containment system mounting procedure is highly automated: reduced number of manual operations
System description – the flat wall area

- The flat wall area
  - The flat wall area is everywhere in the tank, except for the corners and the special areas
The main component of the flat wall area is the "Flat Panel".

- It represents about 90% of all insulation panels used in a tank.
System description – the flat wall area

- The flat panel is a sandwich of several layers

  - Two plywood boards at the top and the bottom of the sandwich
  - Two R-PUF boards as insulating material
  - RSB foil as secondary membrane
  - All these components are bonded together in workshop with PU glue
System Description – The Flat Wall Area

- The flat wall area: flat panels in their context

- **Flat panels**
- **Bottom of the tank**
- **Transverse bulkhead (fore or aft)**
- **Flat panels**
System description – the dihedron

- The dihedron
  - It's the intersection of 2 tank faces
System description – the dihedron

- There are several different dihedron angles (90deg, 135deg, 108.4deg…)
- The two more common angles being 90deg and 135deg.
System description – the dihedron

The insulation panel of the dihedron is called the "Corner Panel"

Typical 90° corner panel

Typical 135° corner panel
System description – the dihedron

The corner panel structure is slightly different from the flat panel one.

Typical 90° corner panel, exploded view.
System description – the dihedron

- The primary level of the corner panel is a bolted assembly of 3 parts:
  - 1 thick stainless steel folded sheet (the "Steel Corner")
  - 2 thick plywood pieces
System description – the dihedron

- The dihedron: corner panels in their context
System description – the trihedron

- The trihedron
  - It's the intersection of 3 tank faces
The insulation panel in the trihedron area is called a "Trihedron" or "Three-way panel"

- The trihedron panel structure is very similar to the one of a corner panel,
- The parts are bonded using the same glues as for a corner panel.
System description – the trihedron

- Exploded view of a trihedron

Typical trihedron, exploded view

- Steel corner
- Plywood
- Closing composite scab
- R-PUF elements
- FSB scab
- Secondary level
System description – the trihedron

- The trihedron: three-way panel in its context

Transverse bulkhead (fore or aft)
Bottom of the tank

Trihedron
System description – completion of the insulation

- Secondary barrier completion
  - The secondary barrier is closed by bonding FSB between panels
Triplex Flexible Secondary Barrier

Sandwich of Glass Cloth and Aluminium Foil
The top bridge pad has the same structure as the primary level of a flat panel:

- Top plywood board
- R-PUF board
- Anchoring strip, riveted to the plywood
The primary insulation is completed by bonding "top bridge pads"
System description – primary barrier

- Membrane sheets are welded on anchoring strips
- The membrane sheets overlap one another
System description - reinforcements

- When needed, several types of containment system reinforcements are available.

For insulation panels

For membranes sheets
System description – reinforcements for insulation

- **Reinforcements include**
  - Denser mastic ropes depositing
  - Thicker bottom plywood (12mm instead of 9mm) for corner panels and three-way panels
Ribs are dents on the large corrugation to increase the buckling strength.

View of a large corrugation with a rib.
System description – reinforcements for membrane

- Plywood wedges are placed below large corrugations, small corrugations and sheets junctions
Mark III Flex: Requirements & Developments

Strength Increase
- The main evolution retained consists in increasing the foam density which provides higher compressive strength
- The Mark III Flex project will take benefit from the “all PU” bonding development

Insulation performance
- The thickness of insulation panels will have to be increased to comply with the conventional 0.15%V/day BOR in case of higher density foam
- The increase of insulation thickness will also provide lower BOR in case of standard density foam use in order to reach an objective of 0.1%V/day BOR
MkIII & MkIII Flex

**MARK III**
270mm

**MARK III FLEX**
400 mm
Mark V
Basis of the development

A new Cargo Containment System

- Based on the Mark III concept
  - Mark III corrugated primary membrane (304L, 1.2mm thickness)
  - R-PUF insulation panels
  - No anchoring of the membranes to the hull
  - Hull requirements consistent with actual Mark III hull scantling

- With new elements
  - Invar secondary membrane
  - Welded secondary membrane

- With improved performances
  - Target Boil-Off Rate: 0.075%V/day
General description

- Corrugated primary membrane identical to Mark III
- Anchoring to the hull with mastic identical to Mark III
- No crossing of membranes
- Corrugated Invar secondary membrane
- Anchoring to the hull with mastic identical to Mark III
NO96 System Components
Objectives

- 1. NO96 design concept
- 2. System description
- 3. NO96 Evolution
1. NO96 design concept
NO96 Tank
1. NO96 design concept

- The NO96 system is a membrane containment system for LNG transportation as defined by the IGC Code, including:
  - Tight thin metallic membranes.
  - Two layers of insulation.

- The NO96 design concept lays on two pillars:
  - A membrane made out of Invar®
  - Plywood boxes filled with an insulating material

- A fully redundant membrane and insulating system.
1. NO96 design concept

- The Invar® membrane:
  - Thickness: 0.7mm
  - Material: Invar® (36% Nickel-Steel Alloy)
1. NO96 design concept

- The insulation boxes:
  - Made of birch plywood or foam panel
  - Filled with insulating material (perlite or GW)
2. System description
Agenda

1. NO96 design concept
2. System description
   2.1. The flat wall area
   2.2. The transverse corner
   2.3. The longitudinal corner
   2.4. The oblique corner
   2.5. The trihedron
2.1 System description – the flat wall area

- The flat wall area: standard boxes in their context.
2.1 System description – the flat wall area

- The secondary boxes cannot be rigidly fixed to the inner hull:
  - The secondary boxes lay on mastic ropes instead of directly onto the hull.
  - Those mastic ropes are used to allow a good bearing of the loads.
  - The secondary boxes are not glued to the hull thanks to a sheet of kraft paper put between the mastic and the hull.
### 2.1 System description – the flat wall area

- Due to the ballast pressure, the hull deforms up to several millimeters between the stiffeners:
  - The secondary boxes cannot be rigidly fixed to the inner hull.
  - The anchoring device of the insulation system must allow for degrees of freedom to compensate for hull deformations.
2.1 System description – the flat wall area

- The anchoring device of the insulation system must allow degrees of freedom to compensate hull deformations:
  - The anchoring device is named “coupler”
  - The coupler is fixed to the inner hull through a ball-joint.
  - The coupler is elastic thanks to spring washers.
2.1 System description – the flat wall area

- Detail view of a coupler and its ball-joint base socket:

  Coupler base socket welded on hull
2.1 System description – the flat wall area

- Coupler deformation under ballast conditions:

![Diagram](image-url)

Spring washers
2.1 System description – the flat wall area

- Coupler and mastic ropes in their context, detail view:

  Coupler

  Mastic ropes

  Kraft paper under the mastic ropes
2.1 System description – the flat wall area

- The insulation of the cargo is completed by filling the gap between insulation boxes:
  - At secondary level, using rigid poly-urethane foam
  - At primary level, using glass wool
2.1 System description – the flat wall area

- NO96 membranes:
  - U-shaped 500mm wide Invar strakes
  - Running from one corner of the tank to the other following some specific directions.
2.1 System description – the flat wall area

- This membranes are fixed to:
  - Each other through seam welds along raised edges
  - The insulation boxes with an invar element named “tongue”
2.1 System description – the flat wall area

- The membrane strakes have to cope with two different kinds of constraint:
  - **Thermal strain** due to the low temperature of the cargo
  - **Mechanical strain** due to the movements of the ship.

- **Invar material** & lateral flexibility through raised edges
- Connection to the ship structure
2.1 System description – the flat wall area

- **Compensation of thermal strain:**
  - Raised edges ensure **lateral flexibility** to the membrane.

Thermal strain absorbed by raised edges lateral flexibility
2.1 System description – the flat wall area

- Compensation of mechanical strain: transmission to ship structure.
  - Membranes are connected to the ship structure (inner hull) through a component named “tube”.

![Diagram showing the connection of membranes to the ship structure through an Invar® tube and the inner hull.](image-url)
Agenda

1. NO96 design concept
2. System description
   2.1. The flat wall area
   2.2. The transverse corner
   2.3. The longitudinal corner
   2.4. The oblique corner
   2.5. The trihedron
2.2 System description – transverse corner

▶ Different angles for TC

▶ Cylindrical tank (n°2, 3 and 4) → 90° angle TC

▶ Tank n°1 (special shape): non 90° angle TC
2.2 System description – transverse corner

- The main component of the TC is the membrane component named “tube”, linking the primary and secondary membrane to the hull.
2.2 System description – transverse corner

- Standard Transverse Corner arrangement:

![Diagram showing Standard Transverse Corner arrangement with annotations for Thermal strain, Mechanical strain, Invar® tube, Invar® strips, and Anchoring flat bars.](image-url)
Agenda

1. NO96 design concept
2. System description
   2.1. The flat wall area
   2.2. The transverse corner
   2.3. The longitudinal corner
   2.4. The oblique corner
   2.5. The trihedron
2.3 System description – longitudinal corner

- Along the Longitudinal Corner, the membrane loads are low (limited bending effect).
2.3 System description – longitudinal corner

▶ The Longitudinal Corner arrangement:

- Invar® strake
- Invar® Angle bar
- Boxes
- Insulation
- Fasteners
Agenda

1. NO96 design concept
2. System description
   2.1. The flat wall area
   2.2. The transverse corner
   2.3. The longitudinal corner
   2.4. The oblique corner
   2.5. The trihedron
2.4 System description – the oblique corner

- The Oblique Corner (OC) is the junction between the upper/lower faces and the chamfers in tank nr. 1.
2.4 System description – the oblique corner

- From the membrane loads point of view, it is a mix of a Longitudinal Corner and a Transverse Corner.

On the lower/upper faces, similar to a Transverse Corner: high membranes loads.

On chamfers, similar to a Longitudinal Corner: low membranes loads.
2.4 System description – the oblique corner

- The anchoring device of the Oblique Corner designed to sustain the membranes loads is named “pillar”.

![Diagram of the anchoring device with brackets](image)
2.4 System description – the oblique corner
Agenda

1. NO96 design concept
2. System description
   2.1. The flat wall area
   2.2. The transverse corner
   2.3. The longitudinal corner
   2.4. The oblique corner
   2.5. The trihedron
2.5 System description – the trihedron

- Trihedron arrangement:
  - Anchoring flat bars
  - Insulation
  - Trihedron
  - Boxes
3. NO96 Evolution – NO96 Max
The Market Drivers

CCS reinforcement

- LNG Carriers
  - Less restrictive for increased flexibility
- Small scale / Bunker vessels
  - All fillings operations are needed for partial loading/unloading
- Offshore (FPSO, FSRU, Ship-To-Ship Transfer)
  - All fillings conditions required by offshore operations are susceptible to generate high sloshing impacts

CCS Low BOR

- BOG needs for propulsion is continuously reduced:
  - Progress made in hull design and propulsion efficiency
  - Flexibility in operation (lower speed, spot market...)

GTT Training

Safety Excellence Innovation Teamwork Transparency
The Market need

Low BOR / CCS reinforcement?
- A compromise based on the shipowner’s need
Concept breakthrough
Based on an efficient structure...

- **The pillar geometry** offers a better strength than **bulkhead geometry**.
  - The bulkhead is subject to **buckling**.
  - The pillar is only limited by the compressive strength of material.

Bulkhead failure: buckling

Pillar failure: compression

- Strength increased by 150%
  - Low inertia $\rightarrow$ Buckling
  - High inertia $\rightarrow$ No Buckling
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The optimized design

Based on NO96 philosophy & sea proven materials

- Invar
- Densified plywood
- Glass wool
- Resin

- Primary invar membrane
- Upper top
- Secondary invar membrane
- NO Max coupler
- Resin patch
- Bottom
- Pillar
- Stiffener
Increased flexibility

Possibility to reach low BOR...

...Or higher strength!

NO96 cross section

Bearing structure = 10% of box volume

NO96 Max Low BOR cross section

Bearing structure = 10% of box volume

NO96 Max reinforced cross section

(B Offshore, heavier gas, partial fillings...)

Bearing structure = 3% of box volume