Offshore LNG transfer: the hard link

Renaud Le Dévéhat[a] Laurent Poidevin[a],
Barend Pek[b], Dave Thomson[c], Jos van Eekeren[b]

a) FMC Technologies SA
b) Shell Global Solutions International B.V.
c) Shell International Trading and Shipping Company Ltd

ABSTRACT

Since the first LNG export occurred in 1963, the LNG industry has demonstrated outstanding offloading system performance. This performance results from the application of rigorous operating and maintenance processes, and the use of proven designs associated with careful innovation progressively developed on field experience and feedback. Major technical progress has been made, but the challenge offered by offshore floating LNG (FLNG) production requires further breakthrough in specific areas. The concept of FLNG is to station a floating processing and storage facility over an offshore gas field so that the produced gas can be liquefied and stored on site. Ocean-going carriers then load the LNG as well as other liquid products for delivery to market. Compared to an onshore facility, operating at sea introduces new challenges including marine issues and working in a remote location. The first FLNG facility when built will be the largest floating offshore facility in the world, with a plot size roughly one quarter the size of a conventional onshore LNG plant. And finally there is the challenge of operating safely directly above product storage tanks, with both the FLNG facility and the offtake vessels moving on the waves.

For the past few years SHELL – a pioneer major in the LNG industry, and FMC Technologies - leader in loading systems, shared their experience and expertise to jointly develop LNG transfer systems that meet the most stringent requirements of (Floating) LNG applications. The companies have previously worked successfully together with the joint development of side-by-side Chiksan loading arms important to offshore LNG receiving terminals. As developments on floating liquefaction have progressed, the two companies recognized that the cryogenic offshore transfer operations required for these export terminals are a critical link in the LNG chain. The most recent joint development project therefore aimed at developing and qualifying safe and reliable solutions for the various offloading scenarios, based exclusively on proven systems, principles and components. This exemplary team work that involved teams of engineers from both companies resulted in the definition and qualification of two systems for offloading from an FLNG production facility. The Articulated Tandem Offshore Loader (ATOL) offers tandem LNG offloading in harsh environments. Whereas the Offshore Loading Arm Footless (OLAF) is designed for side-by-side LNG offloading in more moderate sea states from FLNG production facilities having high freeboard as being considered for large scale production facilities.

The paper will cover the various vital features any LNG transfer system must be able to achieve in order to meet today's requirements for safety, performance, reliability and cost efficiency. It will detail those issues related specifically to the offshore environment including the ability to operate under highly dynamic conditions, the long term reliability throughout a project lifecycle, the stringent safety requirements - including fire safety, integrity, reliable position monitoring, the low pressure loss challenge, the coexistence of sea water and cryogenic conditions, maintainability, as well as the tolerance of the system to unexpected operational events. To meet these requirements, SHELL and FMC Technologies developed over the past few years a comprehensive program for all metal transfer loading arms relying on articulated members based exclusively on field proven components.

Both the side-by-side and the tandem transfer systems for Floating LNG production facilities were considered including activities such as concept selection, detailed safety assessments, ships mooring and positioning analysis including basin tests, engineering and detailed design of the transfer systems using advanced dynamic calculations, control systems detailed engineering, full scale components testing, and complete prototype testing.

SHELL and FMC Technologies are confident that the technologies developed, will ensure safe and reliable offshore LNG transfer operations from the FLNG facility not only for the first cargo transferred, but also for the many subsequent cargoes over the decades of operation of the facility.

Figure 1 Shell's Prelude FLNG concept

A CRITICAL LINK IN AN ENERGY SUPPLY CHAIN

Natural gas is an important source of energy for many of our day to day activities, it can be found in many places all over the world. To bring the gas cost effectively to markets it is often liquefied to reduce its volume by a factor of 600. This liquefied natural gas or LNG is not only a competitive form of gas delivery, it also has a commendable track record for reliability and safety. Natural gas, and by association LNG, offers a cleaner energy source than oil, or coal and less potential human impact concerns than nuclear, important factors in a world increasingly concerned about environmental issues. The strongest advantage of LNG is probably the flexibility of supply. LNG can be transported by sea and to a certain extent on land anywhere in the world, and unlike pipeline gas, buyers are able to source LNG from multiple supply points, providing additional supply security. Overall the international trade in natural gas is set to grow rapidly, but the share of LNG in total gas trade is expected to rise commensurably.

To meet the worlds growing energy demands, bringing new supply sources to market is critical. Natural gas has the advantage that is abundantly available, the International Energy Agency estimates there is some 250 years supply at current consumption rates. Regretfully these resources are generally not easily accessible, they can be located far offshore where land based development might be economically or environmentally challenged. Floating LNG (FLNG) can help unlock these resource. With the LNG liquefaction facility placed directly over the offshore gas resource rather than piping the gas over long distances and processing it on permanent onshore plants, the LNG industry maintains the flexibility that made it economically attractive since the start of commercial LNG activities in the 1960s.

Shell, a pioneer in the LNG industry, and FMC Technologies, a leader in loading systems, have been working on FLNG technology for over a decade. Throughout the technology development both Companies and have put safety, reliability and operability at the core of their design, testing and external approval programs. Personal Safety, Process and Asset integrety are fundamental considerations in the design to ensure the continued safety of LNG operations. The technical maturity of these systems, the market and environmental circumstances now enable the application of FLNG technology for a commercial project that will be followed by other “floaters” in the near term. In May 2011, Shell announced the final investment decision (FID) to build the first FLNG facility to develop the Prelude gas field in the TIMOR Sea, 200 kilometres off Australia’s north-west coast.

The transfer of LNG from an FLNG facility to LNG carriers has captured the imagination of engineers. It is largely recognized that the offshore transfer operation of LNG was amongst the more critical issues in the whole offshore LNG chain, not only due to the technical challenge and the requirement for absolute safety, but also to the need for an outstanding level of reliability. The LNG production relies on the availability of this vital equipment, with any interruption or unavailability for LNG offloading potentially leading to shutting down the unit when the storage capacity is reached, which may compromise the commercial viability of a project.

Since the early development stage of the offshore LNG production more than a decade ago, Shell and FMC have recognized the criticality of this link. Both companies decided to jointly engage in extensive development programs for offshore LNG transfer systems capable of meeting the requirements of potential offshore LNG applications. The result of this partnership now covers side -by-side transfer applications for moderate environmental conditions that enable LNG carriers to berth alongside the FLNG, and a tandem system for harsher environments or for facilities having a higher response to waves and swells. The

Chiksan Offshore Loading Arm Footless (OLAF) is the system selected for side-by-side, while the Chiksan Articulated Tandem Offshore Loader (ATOL) has been designed for tandem configurations.

The LNG industry has demonstrated an outstanding safety record by applying a cautious approach to unnecessary change and the constant integration of lessons learnt, and the two companies have applied similar thinking to the development of offshore transfer systems. Shell and FMC aimed at ensuring at least the same safety level as existing systems for onshore applications. The utilisation of field proven components into the designs not only ensures an outstanding level of reliability, but also enabled the engineers of both companies to focus on the design of the system without developing pioneering components.

PURPOSE OF THIS PAPER

Any discussion on the joint development of the new offshore loading systems is premised on our joint experience with existing loading arms. The unique issues and requirements dictated by operating in an offshore environment will be elaborated in this paper as a background to these programs. The development, features, and components of the OLAF and the ATOL will then be described in order to provide a good understanding of how the companies focused their efforts to develop these key enabling technologies.

To elaborate on the significant overall development period, figure 1 shows the activities that have led to our current position for loading system applications to potential projects

Year	Development phase	Roles
1999	Side-by-side Preliminary study	Join development. Partners.
1997-2000	Joint Industry Project (JIP), Boom to Tanker (BTT) tandem development and dynamic scale testing	JIP, Shell participant, FMC participant and developer
2000-2001	Detailed development targeting system	Join development. Partners.
2002-2003	Targeting system dynamic full scale testing	Join development. Partners.
2007-2008	Conceptual development ATOL tandem	Join development. Partners.
2009-2010	Detailed design and testing ATOL tandem	Join development. Partners.
2011-2012	Conceptual development, detailed design and testing. OLAF, side-by-side	Join development. Partners.

Figure 1: Shell – FMC offshore transfer join developments over the last 15 years

THE FUNDAMENTALS OF LNG TRANSFER

ROBUSTNESS

To develop an offshore LNG transfer systems requires a complete understanding of the fundamental issues that any transfer system must address. The elementary rules of LNG operations based on best practices are paramount and taking “short cuts” in an attempt to solve additional challenges imposed by offshore conditions is not an option.

Although safety will always remain the very first priority in any system developed by Shell and FMC, the requirement for sustainable equipment reliability also dictates the use of robust systems that make no compromise between operational performance and life expectancy. The life cycle required for LNG transfer systems is typically in the order of 25 to 30 years without replacement of a major component. This becomes even more critical in an offshore location where major maintenance is significantly more complex than for most onshore facilities. Ensuring such long term reliability requires a robust solution. The tolerance to unexpected operational events, such as surge pressure events, repeated large movements, operators handling inaccuracies etc, is a key development criterion. Based on decades of operational experience, such robustness has only been demonstrated by all metal transfer systems. Hard articulated systems including the Chiksan loading arms provide a reliable transfer conduit between ships, shore, FSRU or FLNG whilst providing the necessary freedom of movement by incorporating the well proven FMC LNG swivel joints. In terms of fatigue life, the fundamental principle for the design of an LNG transfer system requires the main elements of the equipment to address the anticipated utilization for the complete life of the installation along with the inclusion of appropriate safety factors.

Maintenance obviously remains a key parameter in the long term operation of a transfer system but shall be limited to minor items that can be replaced easily with neither external lifting equipment nor complex handling procedures. This aspect of the LNG operations is critical for a jetty based system, but becomes even more crucial in an offshore environment where additional complications like space for spares storage, accessibility, lifting and handling can simply prevent the possibility of major component replacement.

All LNG terminals in the world are equipped with rigid articulated arms, demonstrating the suitability of this technology for onshore and exposed locations for decades of reliable operations. To name just a few examples, the Shell LNG Brunei crane loading system supplied by FMC in 1976 can be highlighted, with no shipment missed during 23 years of stern loading activities at an exposed location. There are several exposed terminals with no breakwater protection and more than 20 years of operations. In addition, Chiksan LNG loading arms have demonstrated a long life cycle at different locations. Many of these exceeded their design life expectancy and passed 40 years of safe and reliable service. Some are almost 50 years old.

Figure 2: Shell Brunei LNG Crane loading system with stern loading. Exposed location.

FREEDOM OF MOVEMENT

It is a common and simplistic perception that rigid loading arms have only a limited degree of possible movement. The fundamental design of loading arms relies on the basic but essential rules of mechanics to properly configure a combination of hard pipes and swivel joints that guarantee a total freedom of movement between the two sides of the transfer system. Once connected, articulated arms simply follow, in a freewheeling mode, a ship's movement in all translational and rotational movements. With two floating bodies as in the case of an FLNG project, any of the possible movements between two bodies is accommodated by the rotation of the swivel joints. A minimum of six swivels provides freedom in relative surge, sway, heave, roll, pitch and yaw, and it is not uncommon to exceed a reach range of 30 meters even for conventional articulated arms. For example, extremely large LNG carriers are now being loaded/unloaded at conventional onshore terminals with existing loading arm designs already providing the required freedom for all movements.

The kinematics of offshore articulated solutions are no different in this regard to the thousands of loading arms in service for decades for oil, chemicals, LPG and LNG applications. One can simply refer to existing side-by-side articulated systems such as the ship mounted Chiksan LNG DCMA-S loading arms shown in figure 3 below, or to any of the 30+ Chiksan loading arms used on floating units for oil transfers.
All proposed offshore transfer systems - including those using flexible hoses – require a number of swivel joints to ensure sufficient flexibility and limit loads on the systems.

Figure 3: Side-by-side LNG transfer with Chiksan Loading Arms in Dubai

CRYOGENIC COMPONENTS AND SEA WATER: AN UNSUITABLE MARRIAGE

Experience has shown that the cryogenic temperatures of LNG do not match well with a humid environment when it comes to seals or moving parts such as cryogenic valves. Any particle of water immediately turns to ice and can generate sealing and operation troubles at critical interfaces, to the point that all existing LNG loading arms use specific drying systems to eliminate water from the ambient environment in critical areas. This is also the reason why existing LNG transfer systems adopt an aerial configuration and physically separate cryogenic product lines from the sea water surface. In this way, the potential difficulties raised by seawater contact do not add to the complexity of cryogenic components. This also explains why loading buoys – currently used for crude oil transfers – have never been applied for the transfer of cryogenic products.

TRANSFER BOIL-OFF MANAGEMENT:

Vapour handling is a normal feature of any LNG transfer system. Although the majority of heat input and consequent boil off results from the pumping energy, with a closed system there is a requirement to handle displaced vapour and any additional boil off arising from loading to non fully cooled tanks. Any increase in the pressure loss coefficient of the transfer lines also increases the pumping energy which in turn increases the amount of boil off. The pressure drop over the vapour return line is a critical design parameter, as too high a pressure drop could potentially limit the offloading rate.

All systems in service minimize the friction losses through the flat inner surface of rigid pipes and elbows, generally keeping the pressure loss through the whole transfer system below 1 bar (~15 PSI) in a liquid LNG line at the maximum flow rate. Existing loading arms sections sometimes have to use larger diameters than the nominal bore to meet this pressure loss required. Pressure loss is a predominant consideration in the design of transfer equipment.

This explains why all existing transfer systems for LNG rely on rigid pipes which provide an acceptable pressure loss, limiting boil-off and allowing manageable vapour handling.

THE UNIQUE ISSUES OF FLNG OFFLOADING

LNG transfer between onshore terminals in a protected environment and conventional LNG carriers is a well understood activity, with many years experience accumulated since the first days of LNG marine transportation.

About twenty years ago, Shell started to develop terminals at exposed locations with no breakwater protection. For the transfer system, this imposes additional constraints due to the constant movement of the ship during the transfer operation. In the early 1990s Shell and FMC developed LNG articulated transfer solutions for such applications, with the introduction of the Chiksan Constant Motion Swivel Joint that provides the necessary resistance to wear and tear associated with the perpetual motions.

In addition, regular side-by-side transfer from FPSOs with articulated Chiksan arms have been developed since the mid 1970s for various products including crude oil and LPG

More recently, a Targeting System, was developed by the two companies to enable the connection and disconnection of loading arms in more severe conditions at exposed locations including an offshore gravity base type facility and an LNG FSRU.

Courtesy of Yemen LNG

Figure 3 and 4: Chiksan LNG arms with Targeting System on GBS and exposed location applications

Transferring LNG on a regular basis from an FLNG facility brings additional technical issues and challenges. Shell and FMC have together prepared a strong technical team to address this challenge. The latest developments have focused on solving specific constraints. Different site locations and environmental conditions require different solutions to enable transfer operations and so the two companies recently detailed solutions for side-by-side and tandem arrangements. Each system has its own potential and individual project requirements will dictate the selection of the most appropriate solution.

SEA AND SWELL WAVE EFFECT ON VESSELS MOTIONS

The effect of waves on vessel movements has a predominant impact on the design and operation of the transfer systems. Increased vessel movements, particularly at critical frequencies, create design issues that have to be addressed when providing an acceptably operable solution. These include:

- The enlarged dimensions of the operating envelope due to dynamic nature of wave induced motions and the inability to rigidly moor the offtake vessel in a side by side configuration. The relative displacements between the two floating bodies, in combination with the low frequency motions, drifts, draft changes, and additional distances required to safely complete emergency disconnection before the mechanical limits of the systems are reached.

- The accelerations applied at both ends of the system during transfer. This results in complex dynamic phenomena, not only regarding the distribution of the accelerations along the system but also with the frequency response of the system to periodic excitations with random amplitudes and frequencies.

- The higher velocities applied to the hydraulic drive of the transfer systems.

- The feasibility of connecting and disconnecting the transfer system with both sides moving independently.

LNG loading arms for FSRUs already experience these constraints, but the higher exposure of FLNG units in remote offshore locations and the need to maintain adequate operability to maintain offloading before the FLNG tanks become full magnify these challenges.

Other factors to be taken into account:

- The two floating bodies moored alongside each other tend to move simultaneously, with a tendency to limit the relative movements.
- When sufficiently large, the FLNG unit can serve as protection for the LNG carrier against waves.
- The movements at the midship location – where the LNG transfer occurs – tend to be smaller than at bow or stern because of the proximity with the ship's longitudinal centre of gravity.

PHYSICAL LIMITATIONS FOR SIDE BY SIDE OPERATIONS

A side-by-side configuration enables the use of proven arrangements for the loading arms and offers other advantages as described further in this paper. Unfortunately, there are some physical limitations that restrict the applicability of this solution. In particular, berthing operations with tugs and the mooring of vessels alongside can only be achieved in up to moderate environmental conditions.

The tandem configuration can overcome these difficulties as the vessels are not in close proximity. This allows transfers to occur in harsher environments provided the offtake vessel can maintain station astern of the FLNG in a similar manner to tandem crude transfer operations. Typical separation distances ranging from 60 to 100 meters are generally considered as appropriate. In harsh conditions or where there is a distinct separation between wind wave and swell wave components, tandem is the preferred solution, but the transfer system has to be designed to accommodate larger relative excursions between the two ships. For a tandem solution, the following aspects need to be considered in the design:

- Depending on the sea states, offtake vessel positioning in a tandem configuration can be achieved using mooring hawsers or Dynamic Positioning (DP). The transfer system envelope for either of these methods will be greater than in a side-by-side solution due to the increase in wave energy associated with the harsher marine environment.
- The low frequency wave induced movements, including a phenomenon sometimes named "fish tailing", add to the vessel excursions particularly in horizontal movements (surge and sway).
- The two sides of the transfer system are connected at the bow of the LNG carrier and at the stern of the FLNG, the two locations where the pitch movements generate the largest vertical movements.

FREEBOARD DIFFERENCE FOR SIDE-BY-SIDE OPERATIONS

Although in terms of plot space, the Prelude FLNG facility is the size of only one fourth of an onshore LNG production facility, it will be the largest offshore floating facility ever built. With a freeboard in the range of 25 meters, such large scale FLNG units exceed by far the height of typical LNG jetties and the manifold height on board LNG carriers. The increased freeboard makes the use of conventional loading arms more complicated, with particularly long outboard arms required to reach all potential manifold elevations. This in itself is not an issue for the design of the arms, but the loads then applied to the manifold under dynamic conditions may exceed the design criteria for the manifold support on the LNG carrier. However one of the strongest advantages of the side-by-side configuration is the use of existing LNG and LPG carriers and it is not desirable to require modifications to these vessels in order to accommodate additional loads.

This justified the development of the FMC OLAF, which is designed to accommodate the large freeboard difference when connecting to the manifolds of conventional LNG and LPG carriers.

It should be noted here that the transfer of LPG is even more critical in this regard than for LNG as LPG carriers are generally smaller with lower freeboards and the manifold construction is generally not as strong than those for LNG.

As described further, the OLAF has been developed in both LNG and LPG versions.

COST – STANDARD VERSUS DEDICATED LNG CARRIERS

In determining an appropriate offtake solution for a given offshore location, the weather conditions will often dictate what is possible, but there are locations where the concept selection is less clearly defined. Typically the preference would be to select a side by side arrangement where conventional LNG carriers can be loaded compared to a tandem concept where dedicated LNG carriers are required. These carriers would need to incorporate bow loading facilities and most likely some form of Dynamic Positioning and even motion suppression systems. Whatever solution is selected will be associated with a cost although in general terms it is likely that the loading arms, fendering, mooring hooks and space utilization and tug costs in a side by side concept would be cheaper to install and maintain than the construction of a tandem arrangement which also requires the use of dedicated vessels.

To achieve the offloading operability required for an FLNG facility, the environmental conditions of each specific site influence the choice between a side-by-side and a tandem configuration. There is no absolute rule as many parameters need to be considered, but it is generally accepted that side-by-side can be operated up a typical significant wave height of 2 to 2.5 m Hs, while tandem is generally based on conditions reaching ~5.5 m Hs. Again, these numbers represent nothing more than orders of magnitude and other parameters such as wave period, direction, combination of swell and waves, etc, influence the system operability.

Tandem obviously presents strong advantages in terms of availability and suitability for more severe environments, but not without consequences. Unlike side-by-side transfers that can accept any standard LNG carrier, tandem requires a dedicated offtake vessel. A bow manifold arrangement and either a hawser mooring, and/or Dynamic Positioning system is required. Tugs are required for side by side operations to assist with berthing and unberthing but tandem operations may only require a pull-back tug for a hawser based mooring. Any offshore LNG loading operation may expose membrane type LNG carriers to sloshing loads but as the severity of the environmental conditions is likely to be greater where a tandem system is employed, there may be limitations on the use of these vessels with this type of containment.

Overall, there is no absolute choice that meets all projects requirements between tandem and side-by-side solutions, and each project needs to be assessed considering environment conditions, availability and overall system costs. With Shell's Prelude FLNG project, although the two options were available and qualified, the side-by-side configuration with the OLAF has been selected for the LNG and LPG offloading.

FLOATING FACILITIES IN TROPICAL STORM AREAS

Floating production facilities may be located anywhere at sea where there is sufficient water depth and, preferably close to the associated gas field. These locations may be subject to tropical storms as is the case for Prelude FLNG off the Northwest coast of Australia. Wind and wave conditions associated with tropical storms have to be taken into account in the design of the transfer system as the wind loads and motion derived accelerations can be significant. Obviously offloading is not possible during severe weather events but the impact of accelerations under survival conditions on the design needs careful consideration.

The primary function of an offshore transfer system is to maintain a large capability of movement during the transfer, with a system that generally presents a large reach. When it comes to survival conditions with associated high accelerations and wind loads, these primary characteristics are counter-intuitive. Freely moving elements subject to cyclical accelerations could move exaggeratedly and long structures could be sensitive to excessive deflections, resonance, etc…

In the design of the OLAF and the ATOL, special attention has been made to properly secure the moving elements in the stored position so as to avoid any possibility of uncontrolled movement during storms. In this regard, rigid articulated elements are particularly adapted to efficient locking as only a few locking devices, mounted at suitable locations are required to fully secure the system.

Special attention also needs to be taken for the structural design calculations, not only with quasi static stress and deflection calculations but also advanced dynamic calculations taking into account the potential amplification phenomena associated with cyclical motions.

OFFSHORE: THE CHALLENGE OF SPACE LIMITATION

Although the hull of an FLNG facility is large, there remains a significant restriction on available space.

The challenge for the transfer system consists in defining equipment that provides the necessary large reach range in order to follow the possible relative movements during transfer, and that also can be retracted or folded in a compact volume with the smallest footprint possible. The requirement for a complete retraction of the transfer systems is necessary to avoid any interference with berthing or unberthing of LNG carriers.

In side-by-side, this translates into systems stored with no equipment that extends beyond the side of the FLNG. In tandem, the system retracts toward the FLNG so as to provide a complete clearance for the LNG carrier. In the unlikely event of loss of control of the LNG carrier during the approach, the transfer system should remain clear of any potential collision damage.

Maintenance access must be provided within this given footprint for the loading system, without the need for additional external equipment or lifting arrangements. Storage arrangements for spare parts also count in the volume occupied by the offloading system.

HUMAN INTERVENTION TO BE KEPT TO A MINIMUM

For the majority of onshore facilities, the connection and disconnection of the transfer system relies heavily on operator control and in some cases flanging is effected by bolting. Offshore and in the case of exposed onshore berths, the dynamic environment requires the adoption of systems that reduce the potential for personal injury or damage to the transfer system. For a tandem arrangement where the transfer system is connected at the bow of the LNG carrier, physical access is constrained. In the case of side by side transfers, the vessel motions can exceed the ability of the operator to drive the loading arm into a position where the connection can be made. For these reasons, targeting systems are required to enable automatic connection without human intervention. There will always be a need for some operator activity but this can be limited to a minimum and reduce the need for personnel to be in close proximity to the flange connections. The use of sensors and cameras allow the operator to monitor the connection process with an ability to abort the operation.

When connected and during cargo transfer there is no requirement for an operator to remain in the vicinity of the transfer system with adequate instrumented safeguarding, visual monitoring by cameras and gas detection available to identify potential problems in a timely manner.

TESTING AND QUALIFICATION

In the LNG industry, rigorous testing is required before new components, materials or systems are considered acceptable for operational applications. Whilst it may not be possible to exactly replicate the lifecycle operating conditions for a given component, the testing criteria must be sufficiently robust to provide an adequate level of assurance to the operator. This applies equally to transfer systems both onshore and offshore but due to the dynamic environment offshore, the test criteria will be different. For certain components, previous qualification and operational experience at onshore facilities may be insufficient for an offshore application and a new testing campaign is required.

Full scale factory testing of offshore transfer systems is not always possible due to the size of the equipment and the need for very large and complex motion tables to replicate the offshore environment. Testing can be achieved by fully functioning models at 1:4 or 1:5 scale to confirm all aspects of operation, maintenance and system behaviour.

The reliability of a transfer system is critical to the viability of an LNG production facility but becomes increasingly important offshore where the weather windows for product offloading may be less than for an onshore protected berth location and product storage capacity is limited. Strict attention to the proving of components and system reliability is therefore extremely important in the design phases. However, a considerable knowledge base has been accumulated from many years of LNG transfer operations and a premise in the development of offshore systems has been the exclusive use of field proven components, with a sufficient evaluation period in real operating conditions. As described below, the ATOL and the OLAF rely on proven components, and the development effort consisted mainly in validation for offshore application rather than developing pioneering components.

THE USE OF FIELD PROVEN COMPONENTS

In order to describe the development of the OLAF and ATOL it is necessary to describe how experience with field proven components has been incorporated in the design. The following figure gives an overview of the field proven components incorporated in the OLAF and ATOL.

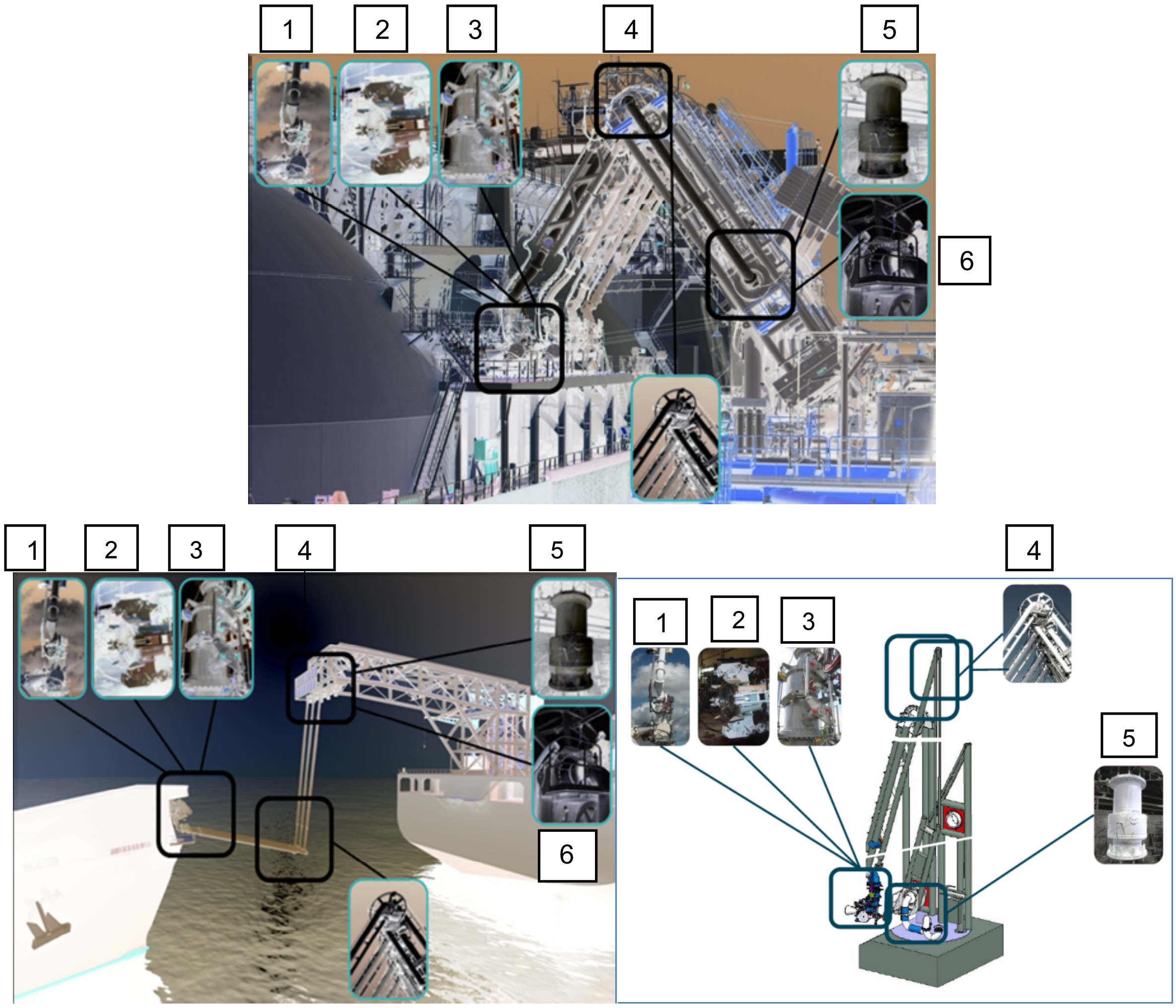

Figure 5: Use of the same Field Proven Components on LNG Loading Arms and on ATOL and OLAF

COMPONENT NAMES:

1	Targeting System
2	Chicksan Hydraulic coupler
3	Emergency Release System (ERS)
4	Style 40
5	Chicksan Constent Motion Swivel Joint
6	In situ maintenance device

The Constant Motion LNG Chiksan Swivel Joint: this swivel joint is typically of 16” diameter but variations up to 24” in are in service and has been installed on more than 100 LNG loading arms. It has demonstrated a significant resistance to wear during testing under cryogenic conditions simulating a 30 year lifetime. The compact cartridge design of the Chiksan swivel joint allows for in-situ replacement with no external lifting requirement, when maintenance is required.

In its standard version, the Chiksan Constant Motion Swivel Joint has some inherent fire resistance characteristics, but an additional option achieves the fire resistance characteristics required by the ISO 10497.

Figure 6: The Chiksan 24” Constant Motion LNG Swivel Joint during running test with external load applied

Figure 7. The Chiksan Swivel Joint during fire safe qualification testing

The Chiksan LNG Quick Connect / Disconnect Coupler (QC/DC), also proven on over 100 LNG loading arms, will be used on the OLAF and ATOL. The robust design is suitable for application in harsh environments. The Chiksan coupler consists of non-reversible hydraulically operated clamps that operate simultaneously and evenly distribute the pre-load on the clamps. A patented -reference 9- device protects the flange face sealing areas from shocks and scratches during the final connection. A dynamic environmental targeting system (see below) considerably limits the relative movement at the final stage of the connection and in combination with the QC/DC minimises the risk of flange or seal damage.

For the ATOL tandem transfer system, the Chiksan LNG QC/DCs are located on the bow manifold of the LNG carrier, to reduce the weight of the ATOL articulated members.

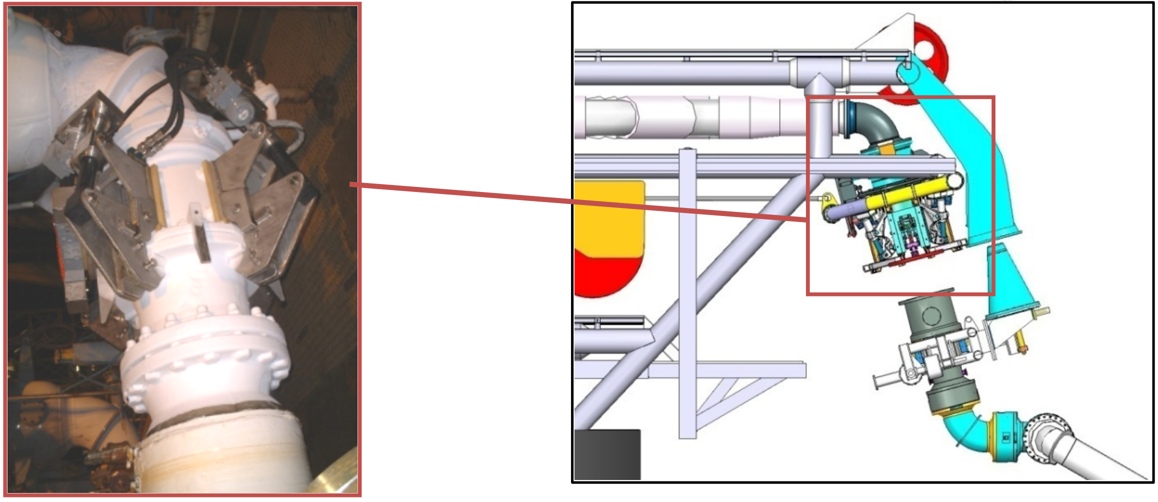

Figure 8: The Chiksan LNG Quick Connect / Disconnect Coupler and mounting on the LNGC ATOL bow manifold

The FMC LNG Emergency Release System (ERS): Similar to any existing LNG loading arm, this key safety device provides the ability to quickly disconnect the OLAF or the ATOL in an emergency whilst preventing the release of LNG. An arrangement of two ball valves connected by an emergency release coupler is dedicated for emergency situations to allow rapid disconnection of the transfer system. The ERS features an in-house design used on FMC LNG arms for nearly 15 years. The key features of the ERS relate to:

- Reliable interlocks to guarantee full valves closure before coupler activation. The FMC design is based on a mechanical interlock that is the preferred industry standard compared to hydraulic interlocks where reliability can be a concern, particularly when improperly used or maintained.
- The fire resistance of the components which need to meet the fire safe requirement of ISO 10497.
- The tight shut off sealing performance of the valves.
- The maintainability of the components.

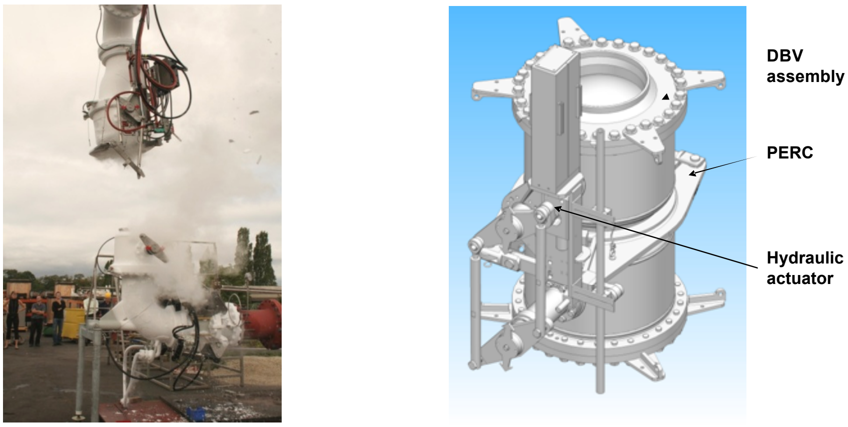

Figure 9: LNG Emergency Release System. Just after disconnection, and main components description

The Targeting System: once connected and during the cargo transfer phase, the system remains fully passive and freely follows the relative movements without need of an active control system. However, the ability to make the connection and disconnection under dynamic conditions is a fundamental challenge that, based on FMC's experience, needed to be addressed in the conceptual design phase. Without a targeting system, there is a risk of collision between the loading arm and the ship's manifold as the arm is hydraulically maneuvered. The targeting system on the OLAF uses the same principle and components as introduced 2000 to connect onshore loading arms to ships moored at exposed berth locations where large and rapid motions can be experienced.

On the ATOL, the system is also largely from the same system, with a further simplification of the original design for the final approach phase.

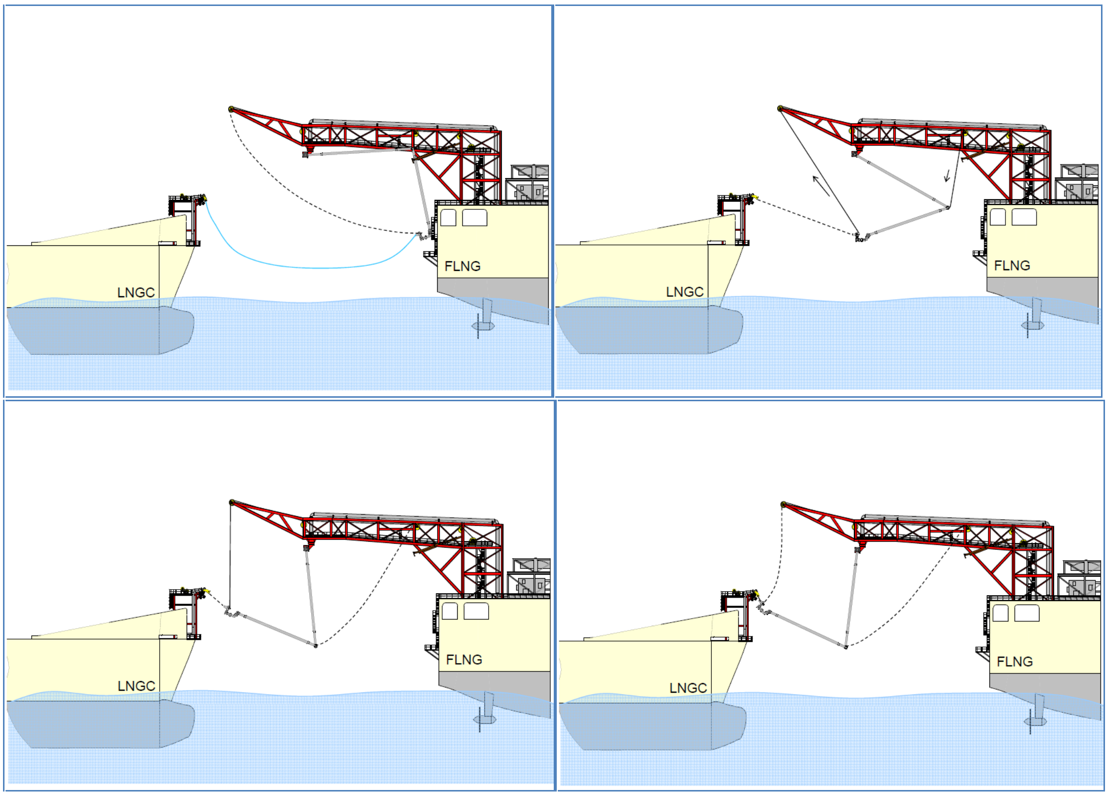

Figure 10: Main steps in the ATOL connection procedure

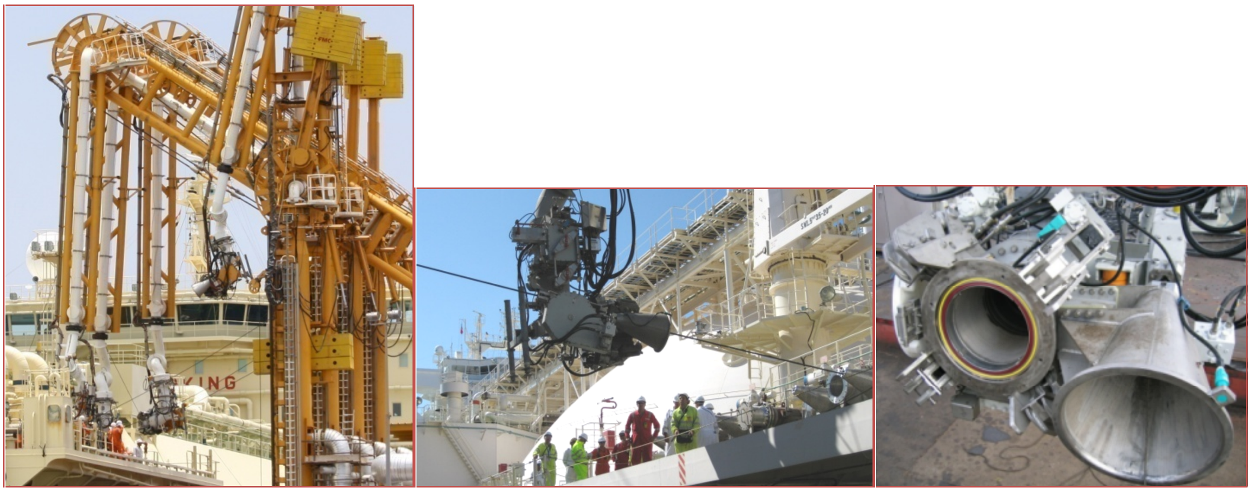

Figure 11: Targeting system in service

DESIGN FOR REAL SERVICE

The developments of the OLAF and ATOL, initiated in 2008 by FMC and Shell, involved a joint team from both companies who followed a comprehensive development programmes for both systems.

These activities included:

- Concept reviews and selection.
- Structured, multi-discipline Safety Basin tests of FLNG and LNGC in a tandem configuration.
- Design and calculations, with specific focus on the dynamic behavior of the structures and the articulated systems. Final calculations are carried out in time domain, so as to assess the dynamic response of these complex systems.
- Components selection, based on field experience record of each component.
- Scale prototype dynamic testing and full scale cryogenic testing.

With nearly 50,000 man hours during development, the systems have now reached a very high level of maturity. OLAF has been further developed for the potential LNG and LPG transfer at the Prelude FLNG facility.

THE OLAF: A COMPACT VERSION OF THE CHIKSAN LNG DOUBLE COUNTER WEIGHT MARINE ARM – STRUCTURE TYPE (DCMA-S).

With a significant difference in freeboard between the FLNG and the LNG carrier, the loading arm design was required to reach the relatively low manifold position of the LNG/LPG carrier. This could be achieved using a conventional loading arm but the articulated members would be prohibitively long. The solution was a revised configuration for the balancing system of the arm allowing the conventional base riser to be removed. On a conventional DCMA-S (left picture), a base riser is required in order to allow the main counterweight to travel without interference. The patent pending OLAF design -reference 8- (right picture) using the same cryogenic components as the DCMA-S places the main counterweight on an independent beam which allows the complete articulated arm to be mounted with no base riser. The “Footless” arm was born.

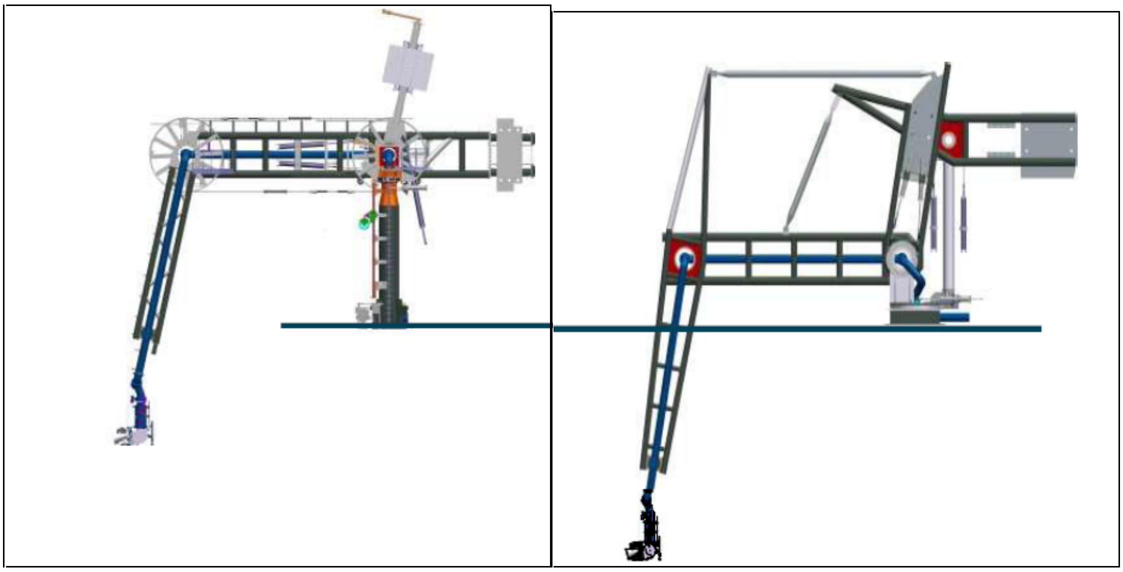

Figure 12: Conventional DCMA-S (left) and OLAF (right)

The advantage of a fully balanced loading arm is maintained, ensuring that no dead weight is applied to the ship manifolds. All the field proven assemblies are re-used, including the complete articulated assembly consisting of outboard and inboard arm structures and product lines, Swivel Joints, Coupler, Emergency Release System, Targeting System, and last but not least the complete control system with its Position Monitoring System.

To reach the same manifold position, the OLAF reduces the length of the articulated members by more than 20% (almost 7 metres) and the weight by 30 to 35% compared to a conventional DCMA-S. This breakthrough is sufficient to avoid modification to LNG/LPG carrier manifolds where a standard arm would produce an overload of the manifolds in severe dynamic conditions.

There are also a number of additional advantages with the OLAF.

On the mechanical side, such a compact arm with no base riser has limited structural deflection and fatigue. Motion amplification and fatigue are limited as the overall assembly is more rigid than when mounted at the top of a base riser. The overall configuration optimizes the loading arms spacing on deck, as the clash between loading arms is easier to manage.
Additionally the mass and centre of gravity are considerably lower than conventional design, a very favourable aspect in an offshore dynamic environment, reducing the loads transferred to the deck and the need for structural reinforcement. Similarly the locking of the arm in the stored position is improved.

Operationally, most critical areas of the arm are directly accessible from the FLNG deck for testing in advance of offloading operations. This includes the triple-swivel joint assembly that comprises the coupler and the Emergency Release System.

Finally, maintainability is improved with easier access to key components due to the compactness of the design. Access to the apex is better, with a reduced elevation, and the main moving elements are directly accessible from deck with no need for ladder, platform or scaffolding.

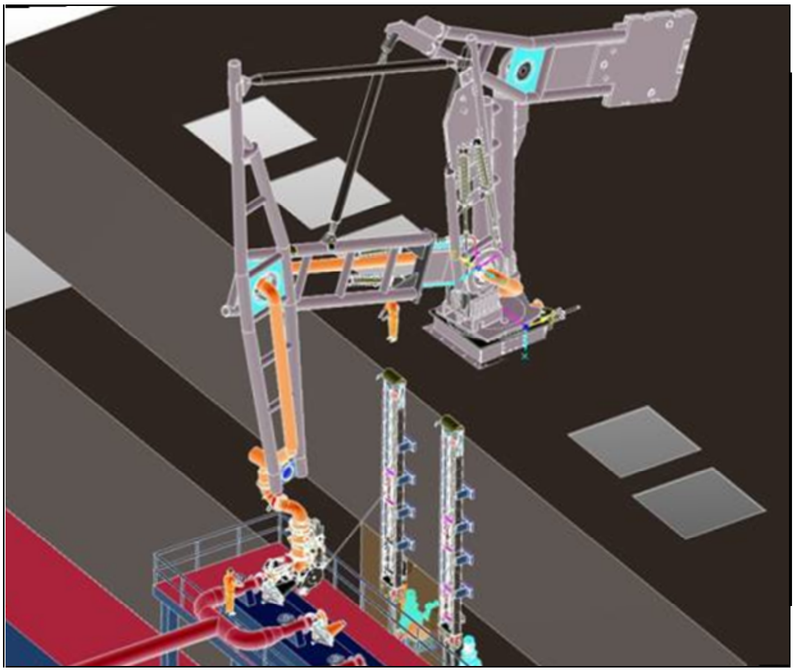

Figure 13: OLAF in connected positions

The development of the OLAF included advanced dynamic calculations in time domain for a large range of conditions, including stored and connected positions, but also when connecting with the FMC targeting system.

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1
DISPLACEMENT
TIME=150
DMX =.423655
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* DCMA OLAF 16"x65' FP LNG* CDC 6
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Figure 14: OLAF time domain dynamic calculation on ANSYS FEA software

THE ATOL FOR MORE SEVERE CONDITIONS IN THE NEAR FUTURE

The ambition of Shell is not limited to Prelude FLNG. Further FLNG projects are expected to be developed to accelerate the development of remote, offshore gas fields which may be located anywhere in the world. The environmental conditions in these various locations are not anticipated to be always as benign as for Prelude, to the point that a side-by-side configuration may not yield an economic operability. The objective of Shell and FMC to develop the ATOL for tandem transfer of LNG was to prepare for these future opportunities.

The two companies based the concept on years of experience in both LNG and offshore operations, and previous research work on tandem transfers of LNG. One such programme was the testing of the FMC Boom to Tanker System (BTT) in 2000. Initially the ATOL development simplified this original concept while ensuring that all the functional requirements were met. In conjunction with Shell's experience of several years operation using a stern loading LNG transfer system in Brunei, the team developed, the ATOL system to a maturity level that will allow future projects to select a tandem concept. The development was completed in 2011 after three years of intensive work.

The basic ATOL features are outlined in the following section.

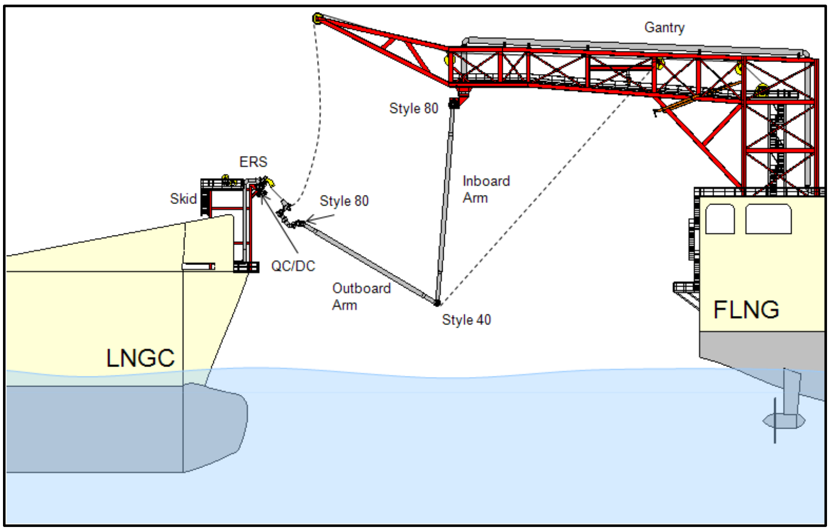

Figure 15: The ATOL concept

The ATOL consists in a configuration of free-hanging fully articulated stainless steel product lines supported by a gantry structure mounted at the stern of the FLNG facility.

Figure 16: the ATOL articulated product lines

The articulated pipes are connected by Chiksan LNG Constant Motion Swivel Joints to accommodate the full range of relative movement, plus a design margin required for the activation of the Emergency Release System (ERS). It must be noted that, on the ATOL, the total number of Chiksan Swivel Joint does not exceed the number of swivels usually used on conventional LNG jetties with loading arms.

The utilization of members articulated with Chiksan Swivel joint provides a unique motion capacity with no compromise on life expectancy and on the fatigue of the cryogenic fluid conduit.
In the design of a transfer system, it is fundamental to verify the compatibility between the range of relative movements encountered during all phases of transfer and the capacity of the system. To that end, the motions of each vessel were first evaluated by basin test in the selected tandem configuration.

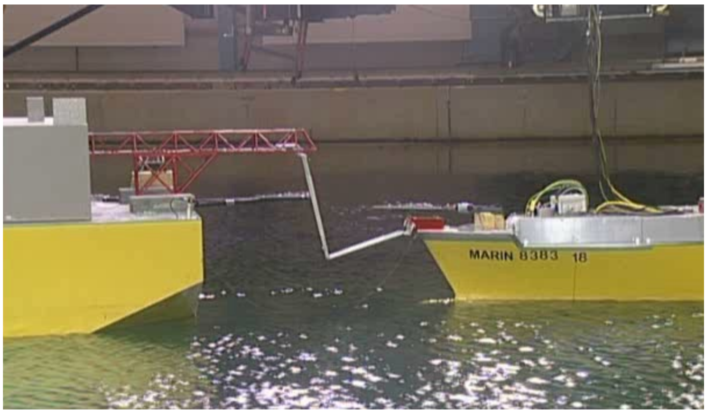

Figure 17: offloading basin tests – Tandem

The Maritime Research Institute in the Netherlands, known as Marin, built a 1:60th scale model of the FLNG facility for Shell, accurate down to the shape and behaviour of the directional thrusters. Testing in their 46 metre x 36 metre state-of-the-art offshore basin, along with mathematical simulation of the FLNG hull and LNG carrier working and moving together, have helped build confidence in the design of the mooring systems, hull structure and off-loading systems, and their capability to withstand extreme weather conditions. The environments tested included both typical North Sea conditions with collinear sea and swell waves and harsh conditions where sea and swell directions are not coincident.

Another fundamental feature is that the system remains fully passive and free-wheeling during transfer, thus avoiding the complexity of actively controlled, repositioning or locking systems.

Figure 18: The ATOL 1:5 scale prototype

The above figure illustrates one of the final steps carried out for the qualification of the ATOL, with the complete testing of a fully functional prototype at scale 1 to 5. This physically validated all phases of operation of the ATOL under a set of dynamic conditions representative of the most severe potential locations for an FLNG facility. The connection, disconnection, stay connected and emergency disconnection sequences were all successfully tested. The test campaign was carried out late in 2010 and was completed early in 2011 at the FMC facility in France.

The scale model was accurately designed to ensure that all aspects of the ATOL dynamic behaviour was verified. A dynamic motion simulator reproduces relative surge, sway, heave, and simulates roll, pitch and yaw angles. The roll motion of the FLNG was also applied on the ATOL side. This feature was implemented in order to validate that there was no risk to excite the free hanging lines when the FLNG rolls. The connection and disconnection are made using a targeting system, which consists of a combination of winches, wires, and alignment devices that have proved to be efficient in all conditions. Emergency disconnection sequences in less than 10 seconds have also been tested, particularly to demonstrate that the system remains above water also during the emergency retraction. The control system that is part of the prototype is the same as full scale control system, and includes a Position Monitoring System (PMS).

All tests were carried out jointly with SHELL and FMC, and a third party attended for qualification purposes. The program was a success with the targets initially set all met.

ON TRACK FOR THE FIRST FLNG AND BEYOND

The Prelude FLNG project is now materializing with OLAF an enabling technology and the clock is now running toward the first LNG offloading. Shell, FMC, and many other key players in this significant step not only see a tremendous challenge being achieved, but also recognize that the doors are now opening to many other opportunities for offshore LNG production and for new momentum to LNG production

The common approach of Shell and FMC to FLNG transfer is to design for safety, applicability over a wide range of field locations and met-ocean conditions and for high reliability and availability. This realistic and practical approach relying on a step-by-step innovation process and nearly 50 years of experience in LNG technology, shipping, offshore and offloading, has proved to be the right combination to provide a sound launch pad for commercialising and applying floating LNG transfer system technology.

We wish to acknowledge the contribution of very many colleagues, predecessors and partners from both companies for all the hard work and creative effort spent in the development of the FLNG offloading technology.

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