THE LOGISTICAL CHAIN, LINKING SHORT SEA AND INLAND WATERWAYS

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SUMMARY

Most of us are familiar with the Airbus A380 project. Being a truly European company means that the production locations of the aircraft are located in different countries. Transportation of the larger parts is done by ship.

The Ro-Ro vessel Ville de Bordeaux delivered by Jinling Shipyard in China to Louis-Dreyfus Armateurs in partnership with Leif Höegh has been built around a whole A380 plane carried in 7 components. A huge cargo space of 120 m long 21 m wide and 11 m clear height without any obstacle or obstruction is reserved for the plane. Bureau Veritas has been actively involved in the design review and new construction in China. The ship sails between Germany, the United Kingdom, Spain and France.

The Ville de Bordeaux arrives at a floating transfer system at Pauillac, France. Tecnitas was deeply involved in various conceptual, structural, mooring and safety studies. The Breuil, built and designed for inland navigation and short sea operation by De Hoop Lobith Shipyard from the Netherlands by order of Socatra, takes the parts inland up to Langdon, after which they go by road transport to the assembling site in Toulouse.

The present paper first describes the logistical chain highlighting the benefit of transport by sea and inland waterways such as the connection between Pauillac and Langdon. In the second part some areas of interest of each project are described. Special attention is given to the impact energy study investigating if the protection of the ancient bridge “Pont de Pierre” would be sufficient to withstand a collision with the Breuil.

1. INTRODUCTION

The Airbus A380 project, the biggest passenger airplane under construction, is a real pan-European project. As such several production locations are scattered over Europe with final assembly in Toulouse. Thanks to dedicated ships the different components can arrive in Toulouse. The total project, the ships, the transfer pontoon and the impact studies for the Pont de Pierre are fine examples of the innovative solutions which can be found by the short sea and inland shipping industry.

In the first chapter we will outline this logistical chain focussing on the involvement of ships. The second chapter will address some of the technical achievements on board of the Breuil and the Ville de Bordeaux. The third chapter will highlight the technical studies carried out by Tecnitas for this project.

2. LOGISTICAL CHAIN

The new Airbus A380 created some challenges for the development team at Airbus. The A380 is revered to as puzzle or Lego which can be seen in figure 1. Typically all of the aircraft Airbus makes are constructed in up to four different countries and the various parts are brought together for final assembly in France. The A380 is no different as its components are built in the UK, Spain, Germany and France, but the size of the A380’s major components means the A300-600 « BELUGA », the distinctively-designed air freighter which normally ferries the main sections of Airbus aircraft, cannot be used. Instead Airbus has devised and requisitioned a land and sea transport network, using specially designed barges, road trailers, and a ferry (see figure 1).

Opting for a multimodal scheme, comprising maritime transport, river barges, harbour cargo loaders and outsized road convoys, besides the five-strong Beluga
A joint venture with leading French ship-owner and dry bulk specialist Louis Dreyfus Amateurs and Norway's Leif Hoegh & Co. has been awarded the A380 maritime transport contract.

The joint venture ordered a ro-ro ship, “Ville de Bordeaux”, from China's Jinling shipyard, near Shanghai.

Major components such as the fuselage and vertical tail unit are manufactured and assembled at the Nordenham, Stade, and Hamburg sites in North Germany. Commercial Final Assembly activities also take place in Hamburg, with all the commercial installations, including the fitting of the cabin interiors, painting, final inspection and eventually delivery to customers in Europe and the Middle East.

The fuselage shells are produced in Nordenham and are then shipped to Hamburg in large special containers using a roll-on-roll-off system. The shipment is done by pontoons being towed by tugs via the Weser and Elbe.

Once in Hamburg, the fuselage shells are assembled in the newly-built Major Component Assembly. The Hamburg plant delivers three A380 fuselage sections: the forward section behind the cockpit, the rear fuselage section, and the upper half of the fuselage shell above the wings which is transported to St Nazaire for further assembly.

In Hamburg, the rear fuselage and part of the forward fuselage are loaded on to the Ville de Bordeaux, a 154 m roll on/roll off (ro-ro) ferry purpose-built for the operation. She sails to Mostyn Harbour in Wales to be met by a barge which has twice travelled 35 km along the River Dee, each time bearing one wing built at Broughton.

Broughton is where final assemble of the wings take place from small components built there and at Filton, near Bristol in North Wales. Built in what is known as the "West Factory" it is believed to be the largest factory built in the UK in recent years with the floor area equivalent to 12 full size football pitches.

Once assembled A380 wings are dispatched individually from the factory by road to the nearby River Dee, then by river-craft, the 800 tonne barge Afon Dyfrdwy to Mostyn where a pair are loaded onto the Ville De Bordeaux for transportation to France.

At St Nazaire she swaps the partly-built forward fuselage for a complete forward fuselage with cockpit as well as a complete centre fuselage. Further on, at Pauillac, the parts, supported on giant jigs, are unloaded on to a pontoon using a multiple purpose vehicle. The vessel then sets off to Cadiz, Spain before returning to Pauillac, France.

Airbus plants in Spain produce the horizontal tail plane, the rear fuselage tail cone and the belly fairing for the A380. They provide Airbus with world-beating expertise in the use of composite materials.

New assembly halls for the A380 horizontal tail plane and belly fairing have been built at Getafe and Puerto Real. At Illescas, innovative technologies are used at the advanced composites centre, allowing for the manufacture of large curvature panels.

The A380 horizontal tail plane is designed and initially assembled at Getafe, with parts manufactured at Illescas, where an extension houses new fibre placement machines. It is then sent to Puerto Real for final assembly and the installation of the hydraulic, electrical, fuel and flight control systems and final testing. The specially-built A380 transport ship, the Ville de Bordeaux, collects the tail plane from Puerto Real for the journey to back to France.

At Pauillac the parts are transferred from the Ville de Bordeaux via a transfer pontoon to a special 78 by 13.8 m barge for a 95 km journey up the river Garonne to Langon (see figure 2). It takes four journeys over one week to move all six major sections for one A380 up the river. They use a variable ballast system and GPS navigation that enables them to pass under bridges even during floods. The trickiest point of the 12-hour journey is passing through the arches of Bordeaux's famous 19th century Pont de Pierre bridge. Then they are transferred via a wet lock to a convoy of trailers.

The convoy then travels 240 km by road to Toulouse and final assembly, always at night and at low speed to minimise disturbance (see figure 3). With two daylight parking stops along the way each journey takes three nights to complete.
As the trailers – with cargoes up to 8 m wide and 50 m long - pass along the route, the drivers are guided by a cabin computer which uses advanced GPS technology to pinpoint to within one centimetre where their trailer is placed in the road.

Figure 3: last traject by road to Toulouse

In Toulouse, the three sections of fuselage are joined together, the wings also joined to the fuselage. The horizontal tail plane is equipped and installed here, as are the landing gears, and the belly fairings. The fin and the rear cone are simultaneously installed. The assembly line is designed to produce four complete aircraft a month but has the capacity to double the production.

3. SHIPS

As discussed earlier several ships are used in the logistical chain. We will discuss two of them in this chapter, without having the intention of making a full description of the ships.

3.1 VILLE DE BORDEAUX

The ro-ro vessel Ville de Bordeaux has been built at Jinling shipyard in China as yard number JLZ02040 (see figure 4). Designed by Deltamarin from Finland, she was delivered in April 2004 to Fret/Cetam, a combination of French Louis Dreyfus Armateurs and Norwegian Leif Hoegh, flying the French flag and classed by Bureau Veritas as:

I HULL I MACH
Ro-ro cargo ship
Unrestricted navigation
STAR-HULL
AUT-PORT
AUT-IMS

Under register number 03378Y.

Figure 4: Ville de Bordeaux

Main Characteristics:

- Length over all: 154,00 m
- Length perpendiculars: 140,00 m
- Breath moulded: 24,00 m
- Depth moulded: 21,85 m
- Maximum draught: 6,50 m
- Propulsion power: 16800 kW
- Speed: 21 kn
- Deadweight: 5200 tonnes
- Hold surface: 6720 m²
- Lane metres: 1800 m

The cargo hold has been specifically designed for the transport of the A380 parts. The individual parts are transported on specially designed TCU’s (transport cargo units), on which they will stay until their arrival in Toulouse. These TCU’s are put on board using MPV’s (Multi purpose vehicle). An example can be seen in figure 11.

The aft ramp/door is the biggest ever fitted on a Ro-Ro vessel, measuring 22 m wide and 13 m high, resulting in a clear opening of 21 m wide and 11.5 m high. The ramp, delivered by TTS (delivered all ro-ro equipment) itself can be loaded with 200 tonnes and the cargo deck have been constructed for a load of 5-10 tonnes/m² (significantly higher than for other typical Ro-Ro designs). Such a large opening necessitated even more attention to the racking analyses than that which is normal for Ro-Ro ships.

In the early design stages beam programs can be used to obtain the first results. Together with the experience built up with earlier racking analyses, the conclusions from the 3D-Beam model (see figure 5) can be used to make the detailed design.
In a later stage the full ship FEM model is made and final verification of some of the detailed structures can be carried out. In this case the FEM model was also part of the STAR-HULL notation which was requested by the owner for this ship.

The additional class notation STAR-HULL is assigned to a ship in order to reflect the fact that a procedure including periodical and corrective maintenance, as well as periodical and occasional inspections of hull structures and equipment, (hereafter referred to as the Inspection and Maintenance Plan) are dealt with on board by the crew and at the owner’s offices according to approved procedures.

The implementation of the Inspection and Maintenance Plan is surveyed through:

- periodical audits carried out at the owner’s offices and on board
- examination of the data recorded by the owner and made available to the Society through an electronic ship database suitable for consultation and analysis
- periodical check of the hull structure, normally at the class renewal survey, against defined acceptance criteria and based on:
  - the collected data from actual implementation of the Inspection and Maintenance Plan
  - the results of the inspections, thickness measurements and other checks carried out during the class renewal survey

The two self-propelled ships have been designed and built at shipyard Hoop international as yard numbers 402 and 403 for the French owner Socatra, flying the French flag and classed by Bureau Veritas as:

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Under register number 03869H (Breuil) and 04319W (Brion).

Main Characteristics:

- Length over all: 75,00 m
- Length waterline: 73,80 m
- Breath moulded: 13,80 m
Depth moulded: 3.55 m
Depth to top of wing tanks: 4.80 m
Maximum draught: 2.60 m
Seagoing draught: 3.00 m
Minimum draught: 1.30 m
Deadweight at T=2.6 m: 1300 tonnes
Deadweight at T=1.3 m: 250 tonnes

**Propulsion**

The propulsion system provided to fulfill the speed and maneuverability requirements exists of two azimuth thrusters (2*735 kW) for a speed of 11 knots (at T=2.60m) at 90% MCR and two forward thrusters (2*400 kW).

The ship has to sail through Bordeaux under the ancient bridge Pont de Pierre where the distance between the bed of the Garonne and the bridge arch is limited. The height of the fuselage section on the pallets is 10.3 m. The difference in the level of the Garonne at low tide between high and low water is 2.65 m.

The consequences of these strict geometric boundaries required a precise design.

Due to the special value of the Pont the Pierre the possible consequences of a collision have been given a lot of attention. The fore ship form has been chosen such as to minimize the damage in case of a collision. In chapter 5 the studies which where performed to determine the optimum shape are further described.

The vessels are build of mild steel for a SWBM of 28000 kNm in Coastal area and 35000 kNm in working area, with double bottom and double sides. Only the double hull is used for ballast capacity and designed to obtain the necessary draft. Above the engine room a deckhouse with accommodation is fitted on rubber blocks to reduce noise and vibration. The wheelhouse is a separate construction with large windows all around to give as far as possible an unobstructed view.

The plane sections are loaded in Paulliac and unloaded in Langon using a multi-purpose vehicle. A harbor ramp is provided on the stern. Cylinders are fitted between Ro-Ro pontoon and barge to reduce relative vertical (capacity 180 tonnes) and longitudinal (capacity 30 tonnes) motion between the pontoon and the ship.

In the hold two lift platforms, minimum breath 8.40 m, flush with the deck when lowered are fitted. The lift platforms are vertically operated, hoisting and lowering is performed by horizontal cylinders build into each platform section deck (capacity 110 tonnes). Each section is locked in the upper position with horizontal cylinders under platform decks and recess into double hull structure of the ships, and provided with a watertight seal with the deck.

In lower position the platforms are in contact with the double bottom. Openings through the platforms and recess in the tank top structure are necessary to allow the pallets legs to go in the lowest position. This low position was needed to achieve the required air draft. However when loading the platform these holes interrupt the transverse beams. A FEM calculation was submitted by the designer of the platform deck, which was verified by a 3-D Beam analysis (see figure 10.).

The heaviest condition for the movable deck is when the MPV is moving the wing and it’s TCU on board. A total static load of close to 200 tonnes has to be carried (see figure 11).

The platform lifts are also reinforced to be loaded with trailers or containers and equipped with lashing points.
The Brueil has received the “Ship of the year” prize in the Netherlands for its innovative design.

4. THE TRANSFER SYSTEM IN PAUILLAC

In the transportation process of the A380 elements, a critical phase deals with the ocean-river interface where cargoes are transferred from the ship to a barge in the river Garonne (see figure 12).

The location chosen by AIRBUS INDUSTRIES at Pauillac in the Gironde offers a rather large access for a safe approach and manoeuvring of the concerned units.

The site is however exposed to current and wind induced waves generated by the local fetch.

4.1 SPECIFIC CONSTRAINTS

The design of the transfer system should in particular satisfy specific requirements in order to minimize standby due to weather limitations:
- acceleration levels on cargos
- relative motions between floating units

4.2 DESCRIPTION OF THE TRANSFER SYSTEM

The system is composed of a pontoon (FTS, floating transfer system) having the following main characteristics:

- Length : 150 m
- Beam : 30 m
- Depth : 7.50 m
- Max. draft : 6.45 m
- Displacement : 28 880 tonnes
The FTS is sliding with collars along two piles along side, with following characteristics:

- Diameter: 2,400 mm
- Thickness range: 25 – 35 mm
- Length: 35 m
- Weight: 68 tonnes

Figure 14: installation of a collar on the FTS

The aft end of the river barge is connected to the downstream end of the FTS in the vertical direction by applying a vertical force as a preload on the pontoon end. This is done by ballasting the aft end of the barge.

The connection is secured by additional specific devices as vertical dampers and fenders in longitudinal and transverse directions.

The river barge is in addition connected to two fender piles along side with.

The main characteristics of the river barge are as follows:

- Length: 75 m
- Beam: 13,80 m
- Depth: 3,55 m
- Mean draft: 2 m
- Displacement: 1660 tonnes

Fender piles system of the barge is composed of two berthing dolphins and one mooring dolphin of 1400 mm diameter with 18 mm thickness on the shore side and 22 mm on the channel side, thickness variations are due to different soil characteristics in order to maintain similar spring characteristics. It should be mentioned (see figure 1) that two barges can be alternatively or simultaneously connected to FTS on the shore side or the channel side.

4.3 ENVIRONMENTAL CONDITIONS

Wind:
- maximum speed from 17 m/s to 20 m/s
- wind speed of 8 m/s is exceeded 2 days per year

Water depth:
Values considered for the design are the following:
- extreme high water depth: 16.50 m (high tide)
- extreme low water depth: 8.80 m (low tide)

Current:
- maximum speed: 2.2 m/s

Sea State:
The site is not directly exposed to waves, but wind generated waves occur as the fetch varies from 3 km (across the river) to 20 km, thus can generate waves from $H_s = 0.75$ to $H_s = 1.60$ m with associated peak periods from $T_p = 2.8$ s till $T_p = 4.2$ s resp. Considering the current effect, the encounter wave frequency can reach $T_p = 6.3$ s.

4.4 A MULTI-BODY SYSTEM

The behaviour in waves of this multi-body system is studied through a linear approach, justified by rather low sea state intensity with regards the size of the units.

Hydrodynamic components are calculated by using three dimensional radiation diffraction software HYDROSTAR, developed by Bureau Veritas.

The various connections are modelled as spring systems calculated from the stiffness values at each connection, linearized around the mean operating value.

The specific vertical connection between the barge and the pontoon generated by a vertical preload is modelled as a unidirectional connection: a force is transmitted in the vertical direction and the corresponding relative motion is suppressed when the other relative motions remain allowed in the orthogonal plane.

Numerous simulations were carried out to validate the global system and optimise the various devices in way of motions and loads minimization:

- Pontoon (FTS): both concrete and steel designs were investigated with for the latter a comparison between a full shape and a catamaran shape. The catamaran version was finally selected.
- Fender piles system of the FTS: the spring system generated by piles and collars is determined to sustain the extreme waves – current – wind loads and avoid as far as possible any resonance in the horizontal plane (surge – sway – yaw components) in the encounter wave frequency range.
- FTS-Barge connection: determination of the preloading, spring and damping characteristics of energy absorbers in the transient period during the preloading operation.
- Barge: spring characteristics of the berthing system compatible with the other spring systems.
4.5 RESULTS

The studies described above and performed by TECNITAS contributed to the definition of an appropriate design of the transfer system in the specific local environment.

SOCATRA, the owner of the two barges, has been operating this transfer system for two years, in quite satisfactory conditions and to the full satisfaction of AIRBUS.

5. STUDY OF IMPACT BETWEEN BARGE AND PROTECTION SYSTEM OF “PONT DE PIERRE”

The purpose of the study was to analyse the collision phenomenon between the barge transporting the parts of A380 aircraft and the devices installed for protecting the bridge piles of “Pont de Pierre” inside Bordeaux city.

The following was investigated:

- evolution of kinetic energies and strain energies in the different elements constituting the system as a function of time,
- accelerations values on the barge,
- behaviour of soils at different levels,
- evolution of displacement at the top of stakes as a function of time.

The hypothesis of a head-on collision in the axis of the protection system was assumed to be the most severe one, the corresponding velocity of the barge being 2 m/s.
The calculations were performed in the context of a feasibility study at the pre-design stage.

5.1 DETERMINATION OF STIFFNESS CHARACTERISTICS OF THE FRONT PART OF THE BARGE

It was assumed that the front part of the barge exhibits plastic deformations during impact. In order to characterize these deformations as a function of the reaction effort induced in way of the contact area, a first finite element analysis was performed using a three-dimensional finite element model of the front part of the barge (from frame 130 to extreme aft end). This model was built up on the basis of available information at pre-design stage using thin shell and beam elements. (See figure 20)

The complete studied system was constituted by the forward structure of the barge and by a fixed cylindrical rigid surface representing the geometry of the stake. Contact between barge and rigid surface were managed by specific elements of ABAQUS software.

Figure 20: ABAQUS Model.

Figure 21: Force versus relative displacement

Loading consists of the application of a prescribed displacement in way of frame 130 for calculating the crushing deformation of the barge under this action and drawing the curve showing the variation of the contact effort as a function of the crushing deformation of the barge. (See figure 21)

5.2 STUDY OF THE COLLISION PHENOMENON

The model used for the analysis was a simple one due to the fact that the study took place at the pre-design stage. The model bi-dimensional constituted by beam elements representing the following components (see figure 22):

- **Stakes**: the protection system is constituted by three stakes. The model assumed that the characteristics of these three stakes are combined for getting the global mechanical characteristics of the system as well as the soils characteristics (represented by non linear springs with elastic–perfectly plastic behaviour).
- **Fender**: this element is fitted at the top of the stakes for absorbing some kinetic energy at the beginning of impact:
- **Barge**: the barge is represented by an equivalent beam. The mass density of this beam is adjusted for matching the global displacement of the barge (2530 t + 10% of added mass of water). The forward part of the barge is represented by a non linear spring having the characteristics determined by the first above described finite element calculations. The barge position in vertical direction is adjusted in such a way that the impact occurs at the top of the stake, which is assumed to be the most severe condition to be withstood by the protection system of the bridge.

Figure 22: The calculation was performed by direct time integration using ABAQUS software. Initial conditions were constituted by an initial velocity of 2m/s for all the nodes belonging to the barge model. Calculations began at the
instant of impact. No damping was considered in the analysis, as this assumption was considered on the safe side.

Curves showing the evolution of the different energies as a function of time are presented on figure 23.

It can be seen that kinetic energy, starting from $5.06 \times 10^6$ J exhibits a minimum value at a time of 1.05 s after impact.

Other results show that:

- Fender is mobilised first, its maximum compressive deformation occurring 0.24 s after impact. At this moment, the fender has absorbed about 8% of the initial kinetic energy.
- After 0.25 s, the remaining kinetic energy is absorbed simultaneously by the deformation of the stakes, by the plastic deformation of the forward part of the barge, and by the deformation of the soils. At the end of the phenomenon, the absorbed energy (in percentage of the initial kinetic energy) is about 43% by plastic deformation of the stakes, 35% by deformation of the soils.
- maximum calculated value of displacement at the top of the stakes is 56 cm,
- it is observed that the soils reach their plastic limit for the mud layer and on about 2/3 of the thickness of the sand layer (up to -12.60 NGF).
- maximum calculated value of acceleration on barge is about 4.6 m/s², which correspond to a value a little lower than 0.5 g.

5.3 RESULTS

Calculation results show that energy absorption occurs first in the fender and then simultaneously in the barge, in the stakes, and in the soils, which correspond to the design target.

Calculated values of acceleration on barge, displacement of top of stakes, and barge deformations are acceptable and validate the system at the pre-design stage.

Figure 23: Energy-Time curves

Figure 24: Safe passage
6. CONCLUSIONS

The total logistical chain involved with the production of the A-380 includes a large number of innovative products and studies which have been initiated and performed by different companies. It shows the power of transport by water, both by sea and on inland waterways. It is a safe and cost-effective method of transport for a complex and valuable cargo.

7. REFERENCES

1. [Nico Guns], ‘[Breuil en Brion, moederschepen voor de Airbus A380]’, [Schip en Werf de Zee], [November 2004]
2. [George Marsh], ‘[Sea change for aircraft transportation]’, [Ship and Boat International], [July/August 2005]
3. [dr. Marc Förster], ‘[Zu lande, zu wasser und in der luft]’, [Aus den Branchen], [Date]
4. ‘[Airbus hybrid ro-ro ship delivered]’, [The Naval Architect], [June 2004]
5. ‘[New era for Hamworthy KSE cargo handling as part of TTS]’, [The Naval Architect], [July/August 2002]
6. ‘[Airbus floating transfer station contract for Remontowa]’, [The Naval Architect], [July/August 2003]

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