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Ground System Studies for landing the CALLISTO vehicle at sea

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Abstract

Recovering a reusable launcher is at any time a difficult challenge. Very often, the launch base location, the technical performance of the launcher added to the flight path and ground sites and population safety constraints does not make possible to recover on land. Recovering at sea is then the straightforward alternative. The CALLISTO Project does not escape from these facts. CALLISTO launch pad being very nearby from the Atlantic Ocean shore, all parameters made it necessary to consider a touch down offshore. But marine environment for rocket landing represents specific constraints compared to ones linked to onshore environment. High sea currents added to swell can make it more difficult to maintain the landing-site at the expected position and also harsher to the vehicle for the final touch down.

In addition, the landing site must be compatible with an easy return to land and a quick passivation of vehicle just after touch down. Economic aspect is not the least as cost of off-shore infrastructures can reach “oil magnate” prices.

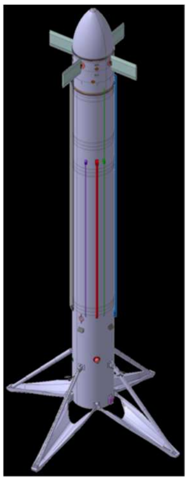
Considering all these constraints (technical, trajectory, safety, cost, etc), the Ground Facilities Development Department of the CNES launcher division undertook an exhaustive study of all the possible systems available nearly “off the shelves” to fulfil the mission for the CALLISTO Vehicle developed in cooperation between CNES, JAXA and DLR. This paper will present the result of this “trade-off” study and will highlight the different pro and cons of the available systems matching to the program and vehicle constraints.

1. Introduction

CALLISTO is a three space agencies partnership: JAXA (Japan), DLR (Germany) and CNES (France).

CALLISTO is a demonstration vehicle with the purpose to demonstrate key features of a reusable first stage in flight that cannot be tested and demonstrated on ground.

With a length of 13 m, CALLISTO vehicle is a single stage vehicle equipped with a 40kN class LOX/LH2 engine, with thrust modulation capability between 40% to 110%.



(Ground and flight) operations (Test & Demo Flights) will be conducted at French Guiana spaceport (CSG).

First flights will evolve in a restricted area, but for the demo flight which will culminate at a height of 35 km, there are safety issues due to the proximity of the town of Kourou.

So for that Demo Flight objective (see fig 1), we have to investigate the potential to retrieve (land) logistic rockets from an offshore platform in French Guiana offshore waters.

The area of interest is located offshore Kourou City, approximately 10 km north west of the Iles du Salut offshore islands within French Guiana waters offshore South America (see fig 2).

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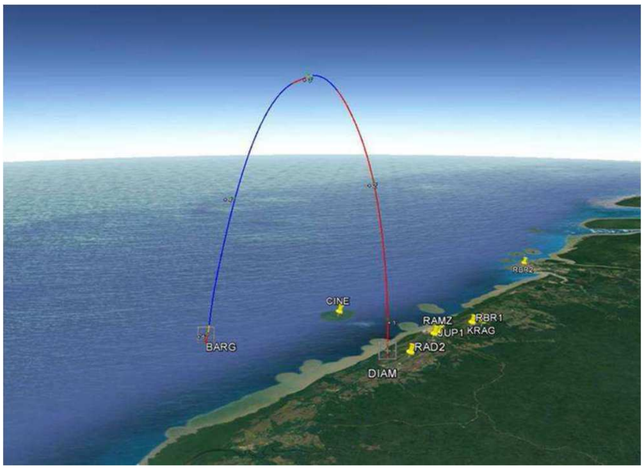

Figure 1: Possible trajectory

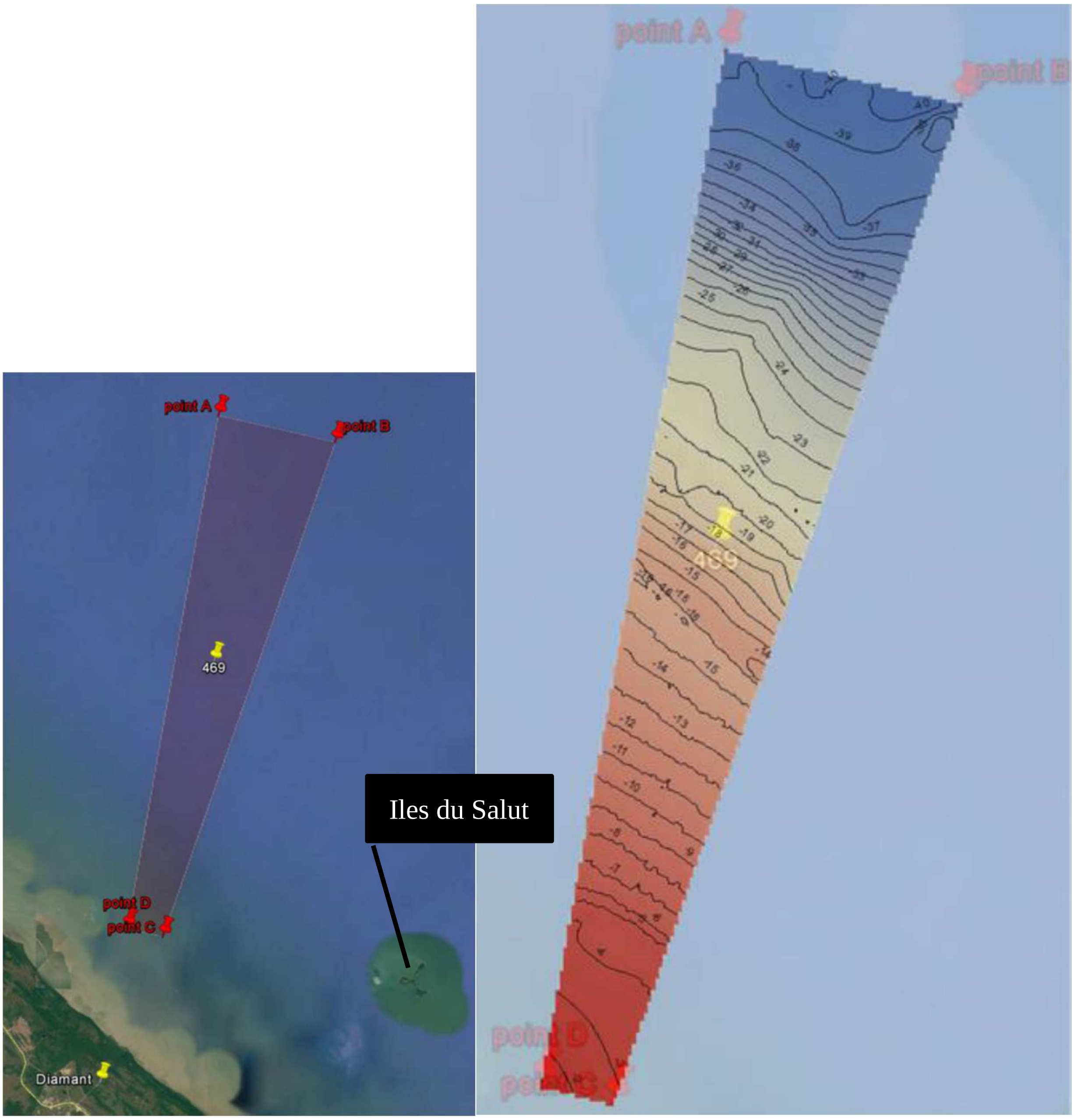

Figure 2: Area of Possible landing and bathymetry (water depth)

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2. Offshore Environmental Constraints

For the study of a dedicated mean, installed offshore, the environmental constraints had to be identified.
Taken from Metocean report [2], environmental constraints (sea) linked to area described Fig 2 are the following:

Table 1:

Depth (m)	17 (medium)	2 (min)	40 (max)
Wave	Hs < 2,5 m	Tp : 8,25 s	North-East (-15°/+15°)
Current (m)	1 m/s	Direction to N-W	

* Hs is significant wave height; Tp is the peak wave period with the highest energy.

In addition, meteorological data, such wind characteristics had also been considered.

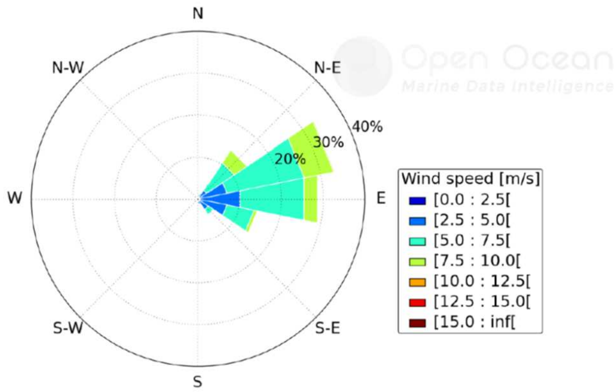

Figure 3: Wind distribution rose at point Project Location (coming from)

3. Offshore platforms survey (benchmark)

The first step was to make a survey of solutions of offshore platforms.

Seven concepts were identified:
- Anchored Floating barge,
- Anchored Floating barge equipped with barge master,
- Floating barge with dynamic positioning,
- Gravity based Foundation, installation with crane,
- Ballasted Foundation by gravity
- Jacket,
- Jack-up,

All these concepts were evaluated according to following criteria:

Table 2:

Criteria	**Evaluation parameter**
Compliance with launcher requirements	Level of movement of the support, no operator on board at touch down
Suitability with transfer operations	Compliance with harbour channel and infrastructure
Technical feasibility	Concept commonly used, compliant with sea environment, with geological ground conditions of the site area, easy installation and maintenance, easy disassembly

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Local impact	Environment impact, social acceptability
Cost	Cost, compliance with local existing means

3.1 Anchored floating barge

For this concept, the barge in question is a Marmac3018 barge type (from McDonough Marine Service catalog).

Table 3:

Hull Characteristics	
Dimensions (m)	96,93 x 29,26 x 6,1
Operating draught (m)	3,05
Weight (including ballast) (t)	7971

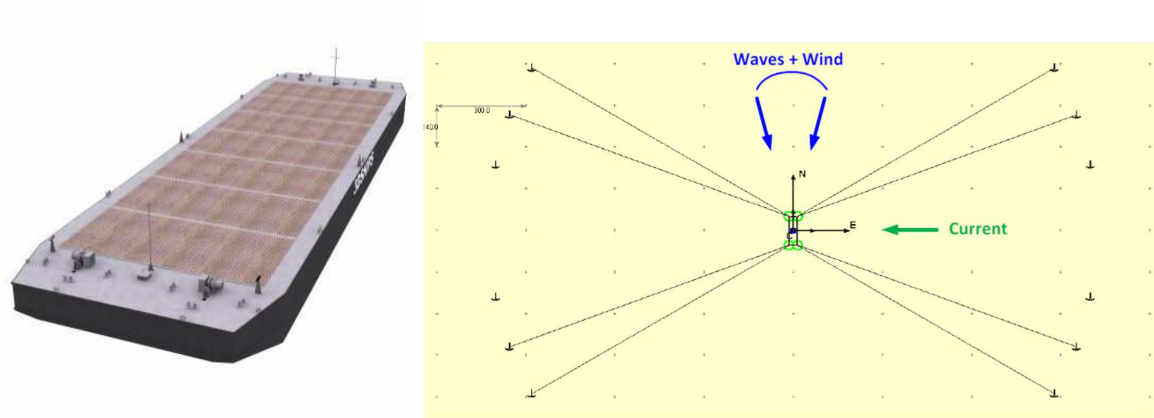

Fig 4 : barge Marmac3018 type with mooring design

A preliminary mooring study has been performed to assess the required mooring components design.
Results are the following, considering a mooring system of 8 mooring lines. The pattern is 1000 m from winch stopper to anchor.

• Mooring winch pulling force: 15 t pull-in capacity, 40 t in brake capacity
• Cable diameter and length: 6-strand wire rope of 51 mm, 1000 m length
• Drag anchor size: 2,5 t

With this design, the behavior of the barge is the following :

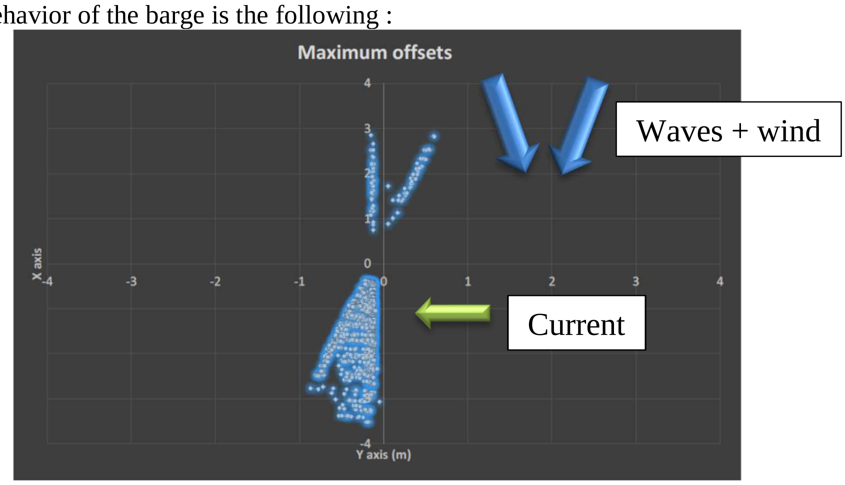

Fig 5: barge maximum offsets (m)

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As per graph above, greatest movements of the barge in horizontal plane are approximately +/- 3,5 m along longitudinal axis and +/- 1 m along transverse axis.
For other movements (roll, pitch, heave), results of simulations give the following: we have 90 % of annual availability of the barge if we accept up to:

- 0,55 m/s2 of vertical acceleration,
- 0,85 ° of roll angle,
- 4,5 ° of pitch angle

To operate this solution, one or two tugs are necessary for the transfer from harbour to the site (and way back). A support vessel for crew access to the barge is also necessary.

Pro and con

PRO	CON
Possibility of renting	Submitted to movements
Economical	Behaviour linked to meteorological conditions
Easy to mobilize and demobilize	Existence of 8 mooring lines (1000m)
Possibility of towing	
Flexibility	

3.2 Anchored floating barge equipped with barge master.

This concept is similar to the previous one with the addition of a device named “barge master BM-T700” associated to a helideck.

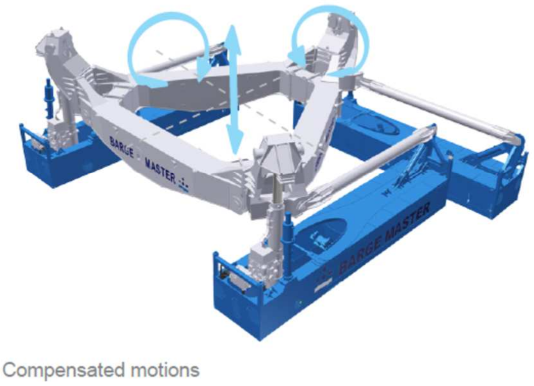

Fig 6 : barge master T700

With this concept, roll, pitch, vertical acceleration is compensated in 75% of sea conditions (considering a year period).

Pro and con

PRO	CON
Possibility of renting	Cost
Movements compensation	Existence of 8 mooring lines (1000m)

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Easy to mobilize and demobilize	Accessibility to helideck
Possibility of towing	
Flexibility	

3.3 Floating barge equipped with dynamic positioning.

Main advantages of a dynamic positioning system are that it allows precise positioning (below 1 m), it is independent from soil conditions and water depth (minimum required: 10 m) and requires no installation time.
In addition, it allows to continuously adjust the vessel heading in order to face the wave and limit the vessel motions.

Main drawbacks are:

- the lack of available barges equipped with dynamic positioning systems in the area,
- costs
- In high sea states, vessel movements could reach high level of amplitude (pitch and roll)
- Fuel consumption
- Cannot be operated where depth is lower than 10 m.

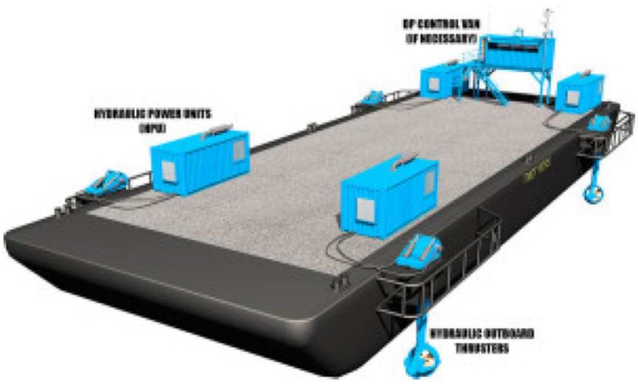

Fig 7 : Barge with dynamic positioning

Pro and con

PRO	CON
Precise positioning	Cost
Flexibility	Submitted to movements
Easy to mobilize and demobilize	Fuel consumption
Independent from seabed conditions	
Compatible with great water depth	

3.4 Gravity based Foundation, installation with crane.

With that type of solution, there is no movement of the platform under waves loads.
The seabed need to be prepared.
The support made of concrete is manufactured in a dedicated factory, then transferred to the site with a barge.
So heavy lifting devices are necessary for its installation on the seabed.
This principle is adapted to depths ranging from 10 to 20 meters

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Fig 8 : Gravity based foundation

Pro and con

PRO	CON
No movement of the platform	Large factory needed for the manufacture
	Submitted to seabed characteristics, and preparation work needed
	Cost
	No flexibility
	Heavy lifting devices necessary for on-site installation

3.5 Gravity based Foundation ballasted

This concept is based on the "float out and sink" offshore installation method.
With that type of solution, there is no movement of the platform under waves loads.
The seabed need to be prepared.
The support made of concrete is manufactured in a dedicated factory, then towed to the site with a regular tugboat.
No heavy lifting device is necessary for its installation on the seabed.
The level of draft of such a device in towed configuration could incompatible with low depth areas.

Fig 9 : Ballasted Gravity based foundation

Pro and con

PRO	CON
No movement of the platform	Large factory needed for the manufacture

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No heavy devices necessary for on-site installation, only regular towing vessels	Submitted to seabed characteristics, and preparation work needed
	Probably a Show stopper linked to low depth of Kourou's harbour channel
	No flexibility
	Low experience return

3.6 Jacket

This concept is built on steel legs, anchored directly onto the seabed. The type of structure used is steel jacket. Steel jackets are structural sections made of tubular steel members, piled into the seabed.

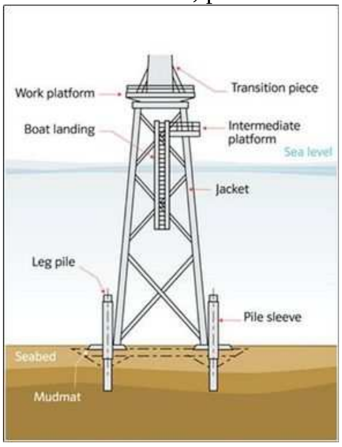

Fig 10 : Jacket

With that type of solution, there is no movement of the platform under waves loads.
The definition of piles is linked to seabed characteristics.
Heavy lifting and pilling devices are necessary for its installation on the seabed.

Pro and con

PRO	CON
No movement of the platform	Pile driving means necessary
	Related to seabed characteristics
	cost
	No flexibility

3.7 Jack-up

A jackup rig is a barge fitted with long support legs that can be raised or lowered. The jackup is maneuvered (self-propelled or by towing) into location with its legs up and the hull floating on the water. Upon arrival at the work location, the legs are jacked down onto the seafloor.

With that type of solution, there is no movement of the platform under waves loads.
The seabed need to be characterised in order to define the level of penetration of the legs in the seafloor. This level of penetration is also linked to shape of spudcans.
No heavy lifting devices are necessary for its installation on the seabed.

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Remaining parts of legs above the plaform could be a problem for landing phase of the launcher.
So, an helideck must be added on the plaform in order to clear the landing surface above these protuberant elements.

Fig 11 : Jack-up

Pro and con

PRO	CON
Easy to operate	Related to seabed characteristics
Flexibility	Compatibility of above part of legs with landing requirements
No movement of the platform	cost

4. Selected Concepts

Among the seven concepts, two were selected:

- Anchored Floating barge equipped with barge master or any device able to filter barge movements,
- Jack-up equipped with a helideck.

For these two concepts, deeper analysis were performed in order to have a better knowledge about their technical feasibility.

4.1 Anchored Floating barge equipped with barge master or any device able to filter barge movements

4.1.1 Survey of compensation devices

The first configuration studied was a classical barge without any compensation device.
Simulations of barge movements, when the barge is submitted to sea conditions described in ref [2], give results of availability versus maximum a chosen movement criteria.

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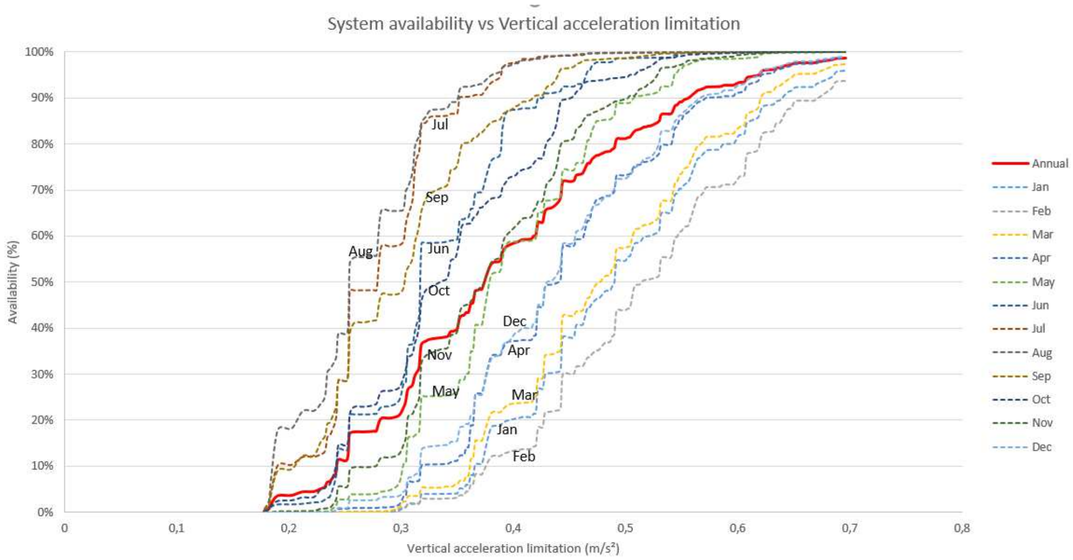

Fig 12

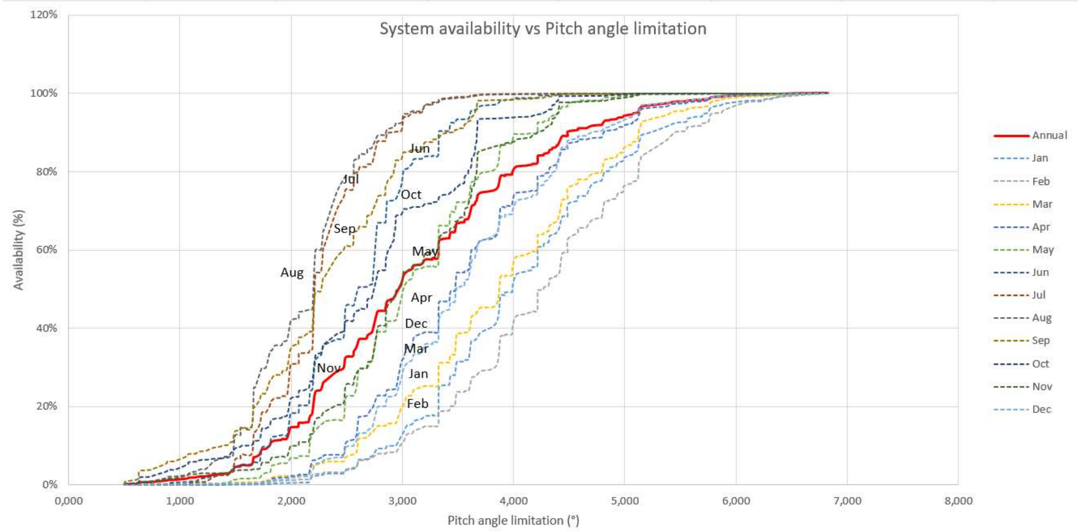

Fig 13

So, for example, if we define a limitation of 3° on pitch angle, the availability for this is 55% annually, but 3% in February, 92% in August

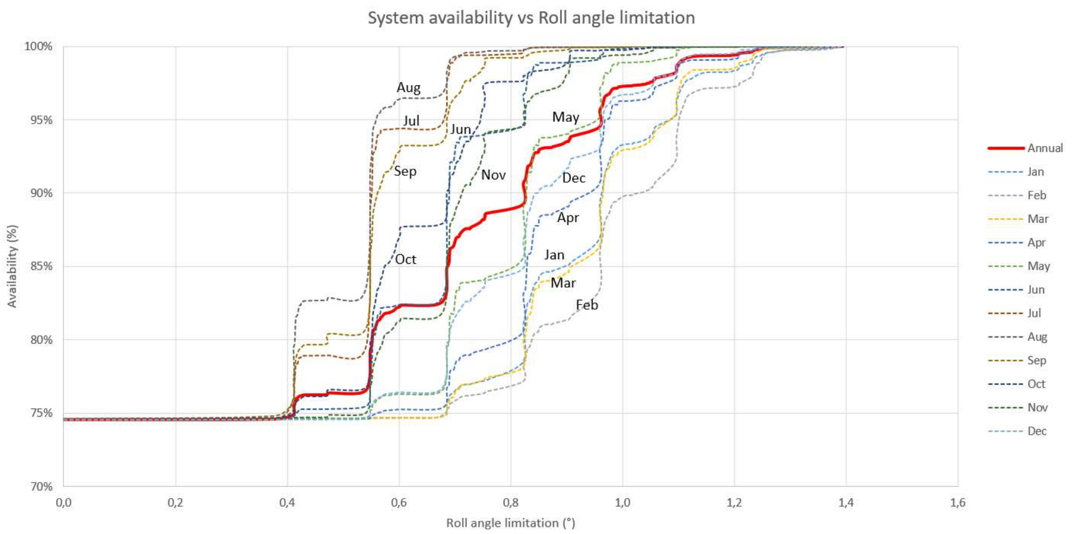

Fig 14

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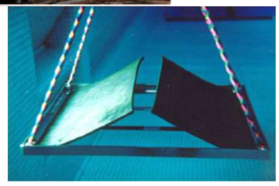
In front of these results, it was decided to search for additional devices to be installed on the barge that could increase the availability by filtering barge movements.

The main solutions found are:

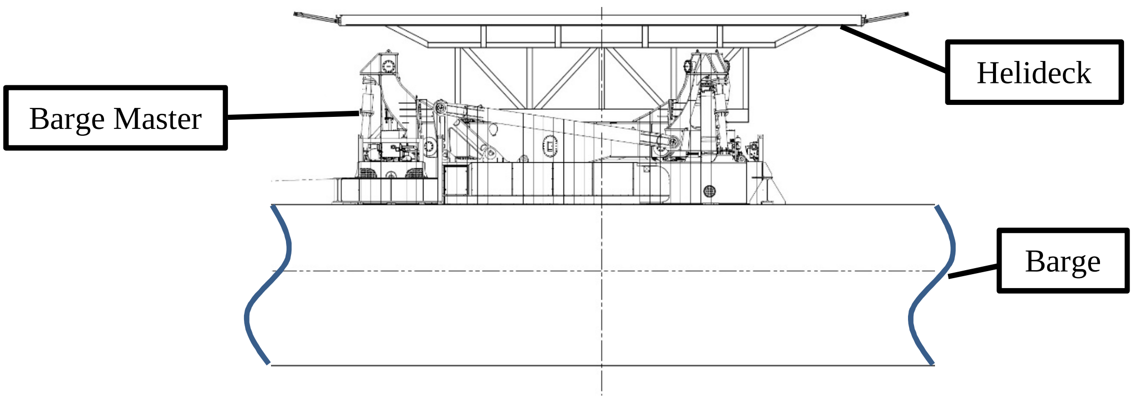


- fin stabilizers : efficient for vessel under motion and mainly on roll (not on pitch)
- floppper stoppers : efficiency difficult to estimate without mock-up tests
- draught ajustement using ballast : this solution does not bring significant improvement
- dynamic displacement of ballast: this solution can only compensate roll movement
- gyroscopic stabilizer: need of huge means in term of electrical supply and expensive solution
- barge master : with a payload capacity of 700 t, the considered concept is to set up this device on the barge and to add an helideck on it.

4.1.2 Anchored floating barge equipped with barge master and helideck concept study

This concept uses a barge master T700 with an helideck installed on it.
The BM-T700 measures vessel motions and actively compensates roll, pitch and heave motions by means of three hydraulic cylinders.It is able to compensate up to 95 % in the following sea environment : Wave height Hs 0 - 2.5 m, Wave period 4 - 18 s

Taking into consideration sea conditions existing in the area of our interest (described in ref 2), BM-T700 compensates roll, pitch and heave in 75% of sea conditions we could have during a year.
This result comes from the analysis of the following Hs-Tp annual scatter diagram which describes sea conditions.



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	Hs_bin [m	0.00	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	
Tp_bin [s]		0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00	3.25	3.50	Total
0.00	0.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.50	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.00	1.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1.50	2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	2.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.50	3.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.00	3.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3.50	4.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
4.00	4.50	0.00	0.00	0.00	0.04	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08
4.50	5.00	0.00	0.00	0.00	0.12	0.46	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.65
5.00	5.50	0.00	0.00	0.00	0.06	0.45	0.46	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.99
5.50	6.00	0.00	0.00	0.01	0.06	0.12	0.21	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.48
6.00	6.50	0.00	0.00	0.03	0.17	0.15	0.20	0.11	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.66
6.50	7.00	0.00	0.00	0.14	0.58	0.73	0.79	0.33	0.05	0.01	0.00	0.00	0.00	0.00	0.00	2.63
7.00	7.50	0.00	0.01	0.51	1.74	2.04	2.39	1.28	0.27	0.03	0.00	0.00	0.00	0.00	0.00	8.27
7.50	8.00	0.00	0.01	1.37	3.60	3.61	3.35	2.24	0.59	0.07	0.01	0.00	0.00	0.00	0.00	14.85
8.00	8.50	0.00	0.01	2.55	7.24	6.64	5.50	4.37	1.68	0.28	0.03	0.00	0.00	0.00	0.00	28.29
8.50	9.00	0.00	0.00	1.04	3.51	2.77	2.35	2.49	1.38	0.34	0.05	0.00	0.00	0.00	0.00	13.93
9.00	9.50	0.00	0.00	0.33	1.67	1.56	1.22	1.44	1.12	0.38	0.05	0.01	0.00	0.00	0.00	7.77
9.50	10.00	0.00	0.01	0.24	1.05	0.79	0.66	0.79	0.61	0.32	0.07	0.01	0.00	0.00	0.00	4.54
10.00	10.50	0.00	0.00	0.05	0.39	0.43	0.27	0.20	0.15	0.10	0.05	0.01	0.00	0.00	0.00	1.65
10.50	11.00	0.00	0.00	0.15	0.84	0.82	0.42	0.20	0.14	0.08	0.03	0.02	0.00	0.00	0.00	2.70
11.00	11.50	0.00	0.00	0.03	0.24	0.35	0.18	0.06	0.02	0.00	0.00	0.01	0.00	0.00	0.00	0.88
11.50	12.00	0.00	0.00	0.04	0.47	0.64	0.39	0.13	0.04	0.00	0.00	0.00	0.00	0.00	0.00	1.71
12.00	12.50	0.00	0.00	0.03	0.33	0.57	0.34	0.15	0.02	0.00	0.00	0.00	0.00	0.00	0.00	1.44
12.50	13.00	0.00	0.00	0.01	0.24	0.55	0.35	0.20	0.03	0.01	0.00	0.00	0.00	0.00	0.00	1.40
13.00	13.50	0.00	0.00	0.02	0.20	0.58	0.39	0.26	0.06	0.02	0.00	0.00	0.00	0.00	0.00	1.53
13.50	14.00	0.00	0.00	0.00	0.08	0.27	0.22	0.17	0.06	0.01	0.00	0.00	0.00	0.00	0.00	0.81
14.00	14.50	0.00	0.00	0.00	0.15	0.52	0.46	0.37	0.24	0.07	0.01	0.00	0.00	0.00	0.00	1.82
14.50	15.00	0.00	0.00	0.00	0.07	0.18	0.20	0.17	0.12	0.04	0.01	0.00	0.00	0.00	0.00	0.80
15.00	15.50	0.00	0.00	0.00	0.02	0.06	0.07	0.08	0.05	0.02	0.00	0.00	0.00	0.00	0.00	0.30
15.50	16.00	0.00	0.00	0.00	0.04	0.16	0.19	0.16	0.12	0.06	0.02	0.00	0.00	0.00	0.00	0.74
16.00	16.50	0.00	0.00	0.00	0.02	0.10	0.10	0.11	0.05	0.04	0.01	0.00	0.00	0.00	0.00	0.44
16.50	17.00	0.00	0.00	0.00	0.00	0.03	0.03	0.03	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.13
17.00	17.50	0.00	0.00	0.00	0.00	0.03	0.03	0.02	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.13
17.50	18.00	0.00	0.00	0.00	0.01	0.06	0.06	0.06	0.03	0.03	0.00	0.00	0.00	0.00	0.00	0.25
18.00	18.50	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.03
18.50	19.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04
19.00	19.50	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.04
19.50	20.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02
20.00	20.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01
20.50	21.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21.00	21.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21.50	22.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22.00	22.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total		0.00	0.03	6.57	22.93	24.75	20.93	15.54	6.87	1.96	0.36	0.06	0.01	0.00	0.00	100.00

Fig 15

As an example, following table shows the impact of the use of BM-T700 on pitch movement of the barge.

Pitch max (°) Hs / Tp	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75	9.25	9.75	10.25	10.75	11.25	11.75	12.25	12.75	13.25	13.75	14.25	14.75	15.25	15.75	16.25	17.75
0.75					1.16	1.38	1.57	1.74	1.89	2.00	2.09	2.16	2.21												
1.00	0.51	0.70	0.95	1.24	1.54	1.83	2.10	2.33	2.52	2.67	2.79	2.88	2.95	2.99	3.02	3.03	3.04	3.04	3.02	3.01	2.98				
1.25	0.63	0.88	1.19	1.55	1.93	2.29	2.62	2.91	3.15	3.34	3.49	3.60	3.68	3.74	3.77	3.79	3.80	3.79	3.78	3.76	3.73	3.69	3.65	3.61	3.47
1.50	0.75	1.07	1.43	1.86	2.31	2.75	3.15	3.49	3.77	4.01	4.19	4.32	4.42	4.49	4.53	4.55	4.56	4.55	4.54	4.51	4.47	4.43	4.38	4.33	4.17
1.75			1.67	2.17	2.70	3.21	3.67	4.07	4.40	4.67	4.88	5.04	5.16	5.23	5.28	5.31	5.32	5.31	5.29	5.26	5.22	5.17	5.12	5.06	4.86
2.00						3.67	4.19	4.65	5.03	5.34	5.58	5.76	5.89					6.07	6.05	6.01	5.96		5.85	5.78	
2.25							4.72	5.23	5.66	6.01	6.28	6.48	6.63							6.76			6.58		
2.50										6.68	6.98														

Fig 16 : max pitch without barge master

Pitch max (°) Hs / Tp	4.75	5.25	5.75	6.25	6.75	7.25	7.75	8.25	8.75	9.25	9.75	10.25	10.75	11.25	11.75	12.25	12.75	13.25	13.75	14.25	14.75	15.25	15.75	16.25	17.75
0.75					0.20	0.20	0.20	0.20	0.20	0.20	0.21	0.22	0.22												
1.00	0.20	0.20	0.20	0.20	0.20	0.20	0.21	0.23	0.25	0.27	0.28	0.29	0.29	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30				
1.25	0.20	0.20	0.20	0.20	0.20	0.23	0.26	0.29	0.31	0.33	0.35	0.36	0.37	0.37	0.38	0.38	0.38	0.38	0.38	0.38	0.37	0.37	0.37	0.36	0.35
1.50	0.20	0.20	0.20	0.20	0.23	0.28	0.31	0.35	0.38	0.40	0.42	0.43	0.44	0.45	0.45	0.45	0.46	0.46	0.45	0.45	0.45	0.44	0.44	0.43	0.42
1.75			0.20	0.22	0.27	0.32	0.37	0.41	0.44	0.47	0.49	0.50	0.52	0.52	0.53	0.53	0.53	0.53	0.53	0.53	0.52	0.52	0.51	0.51	0.49
2.00						0.37	0.42	0.47	0.50	0.53	0.56	0.58	0.59					0.61	0.60	0.60	0.60		0.58	0.58	
2.25							0.47	0.52	0.57	0.60	0.63	0.65	0.66							0.68			0.66		
2.50										0.67	0.70														

Fig 17 : max pitch with barge master

It can be noticed that the BM-T700 does not compensate horizontal movements of the barge , so original ones remain as mentioned in chapter 3.1.

As a summary, maximum values of residual movements are:

Maximum values	Stabilized barge
Roll amplitude (°)	0,2°

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Pitch amplitude (°)	0,7°
Longitudinal displacement (m)	+/- 3,5
Lateral displacement (m)	+/- 1
Heave amplitude (m)	2,23

All necessary support devices for post launch operations will be installed on the deck of the barge during its preparation at Kourou harbor.

Items of equipment will be stored inside containers: - mechanical tools, - bundles of cylinders (for flushing operations), - fluid panels, - communication and video means, - weather center, - firefighting system, - power supply. A boom lift will be also present on the barge.

The transfer from Kourou harbor to landing area will be performed by using classical tug.
After landing phase, two options are considered for launcher return to on ground facilities: helicopter transport or towing of the barge back to Kourou harbor, with launcher secured on it.

4.2 Jack-up with helideck

In order to better estimate the feasibility of a such solution, first points to analyse are characteristics of seabed in the selected area.

4.2.1 Geotechnical parameters

On the base of existing data (SHOM, BRGM, Admiralty chart, bore-hole cartography (Pujos)), it is difficult to have a precise idea of soil profile.
So two hypotheses were taken for the prediction of leg penetration: a shallow bedrock case (5 m) and deep bedrock case (20 m).

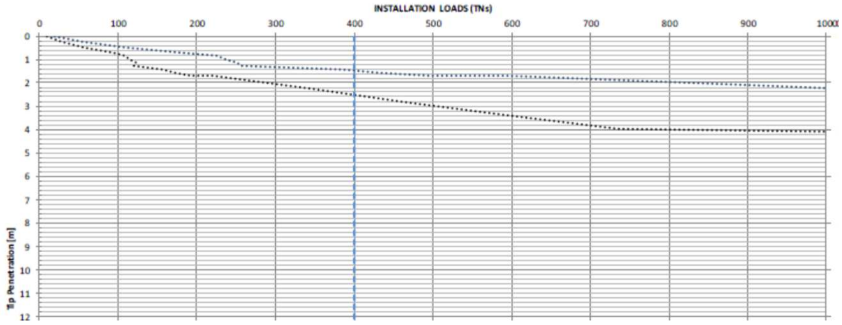
	Soil	Depth, z (m)	
		From	To
1	Silt/Mud	0	1
2	Clay/Sand	1	5
3	Igneous Rock**	5	>20

Shallow bedrock hypothesis

Unit	Soil	Depth, z (m)	
		From	To
1	Silt/Mud	0	1
2	Clay/Sand	1	20
3	Sandstone	20	>50

Deep bedrock hypothesis

Depending on these soil parameters, leg penetration prediction is between 1,5 to 4m.
These elements allow us to go further with this design.



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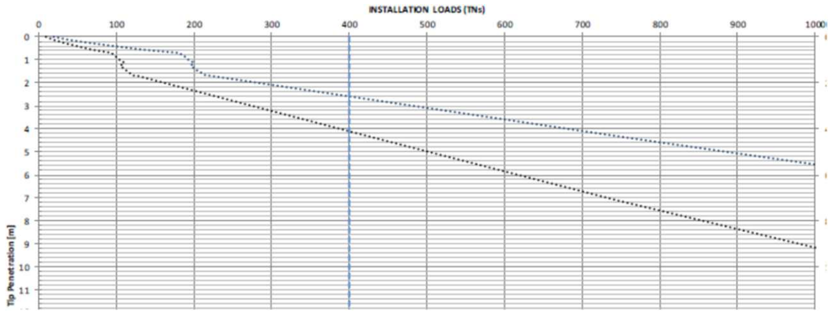
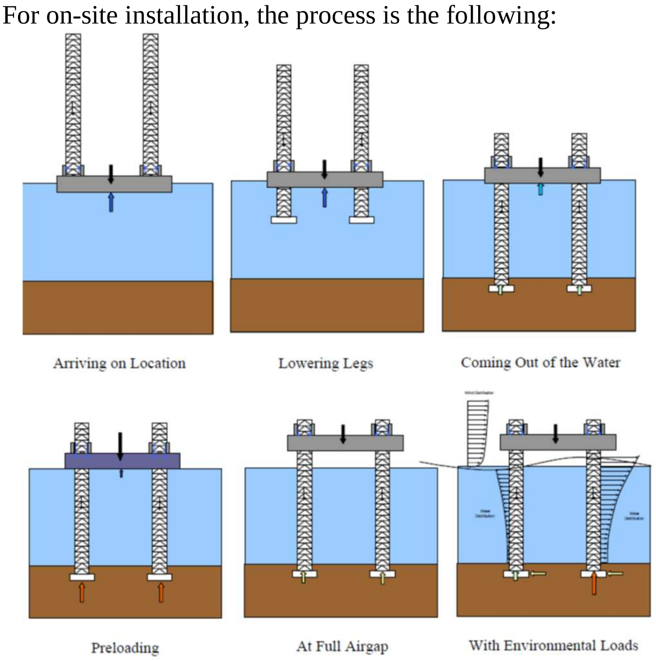


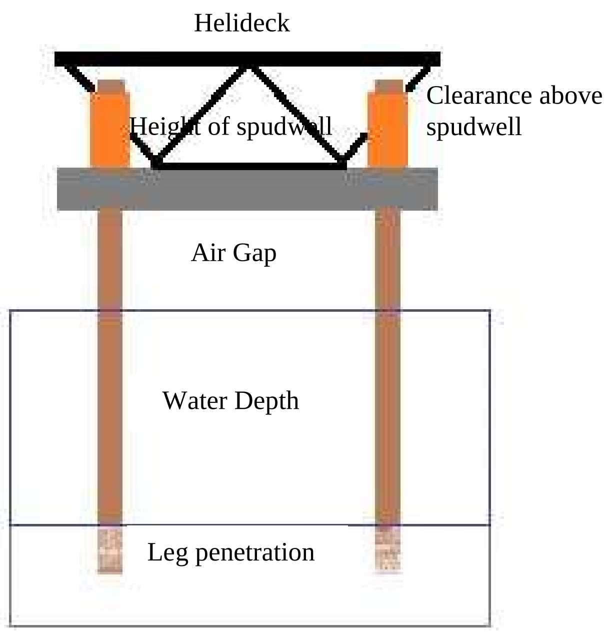
Predicted penetration profiles

In any case, on site survey will be necessary to precisely determine the characteristics of soil in the selected area.

4.2.2 Jack-up concept study

Taking into account constraint coming from the launcher, the selected Jack-up has a desk of a size of 36,6 x 27,4 m and is compatible with a depth up to 45 m.
As described in the previous chapter, we have a first estimation of leg penetration from 1,5 to 4 m, depending on soil characteristics.
For on-site installation, the process is the following:





Several parameters need to be managed:

- One is the Air gap (distance between lower part of the hull and maximum level of sea (tide and heave)): a classical value is between 8 and 10 meters in our sea conditions.
- The second is the remaining length above the desk of the jack-up: this length must not be above the landing surface (helideck)

Depending on characteristics of chosen site (soil, water depth), length of the legs will be adjusted in order to fulfill the two above parameters.

As for barge solution, same support devices will be installed on the deck jack-up.

The transfer from Kourou harbor to landing area will be performed by using classical tug.

For the jack-up solution, one particular point to consider is the way to access: with a foreseen air gap between 8 and 10 meters during operational configuration, the level of elevation of the jack-up could be adapted and decreased in order to ease access to jack-up deck during these phases.

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As for the other concept, for the “after landing phase” and mainly launcher return to on ground facilities, we will have to choose between the following two options: helicopter transport of the launcher or the towing of the jack-up back to Kourou harbor, with launcher secured on it.
This trade-off can be made separately as it does not depend on the type platform chosen.
Nevertheless, when considering the helicopter scenario, sea conditions during travel back to Kourou harbor don’t need to be considered.
For return option to Kourou harbor by sea, way of securing the launcher on the platform has to be assessed.
Thanks to barge master installed on the barge, conditions during this phase could be less stringent than one expected for the towed jack-up configuration.

5. Conclusion

Test and demo flights of CALLISTO launcher demonstrator will be conducted in French Guyana. As some foreseen trajectories generate safety issue due to the proximity of the town of Kourou, an analysis of possible solutions to retrieve (land) logistic rockets from an offshore platform in French Guiana offshore waters was performed.

The two main concepts emerge from this search: a barge concept equipped with barge master and helideck and a concept of jack-up with a helideck.

The concept of jack-up offers a high level of stability of the deck. But, as legs of jack-up rest on seabed, first of all on-site survey (geotechnical and geophysical) of seabed must be performed in order to confirm the correct ground conditions.

The concept of barge with barge master offers a good level of compensation of barge movements, some residual movements remain in the case of exceptional sea conditions. The environmental impact of the use of 8 mooring lines had to be assessed.

Further analysis of the two concepts need to be conducted, especially about economical subjects and compatibility with flight control system at landing phase.

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