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THE DYNAMICS OF FLEXIBLE JUMPERS CONNECTING A TURRET MOORED FPSO TO A HYBRID RISER TOWER

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ABSTRACT

Hybrid Riser Towers (HRTs) have been demonstrated to operate when connected to spread-moored FPSO's in West Africa. As Turret-moored FPSO's projects are appearing in the Gulf of Mexico (GOM) and Brazil; it is necessary to have a closer look at the impact of harsher metocean conditions and possibly smaller FPSO hulls.

Assessments of jumper interference of HRT configurations for Brazil Campos Basin and Gulf of Mexico conditions were carried out. Criteria were developed to quantify the magnitude of the forces acting on downstream jumpers. The interference criteria cater for static and dynamic conditions and account for wake shielding and wake instability. Calculations in GOM conditions accounted for strong currents such as eddy, Loop, and submerged currents. Wake-interaction contours were then developed to describe the lateral and longitudinal extent of the wake, within which, there is significant potential for downstream jumper displacement and interference. The criteria were efficiently applied to determine which jumpers were most prone to potentially damaging wake interference.

The HRT comparison in Brazil and GOM is summarized. With this respect, the results of the study confirmed that a HRT system could be applied to a turret-moored FPSO in the Brazilian and Gulf of Mexico environments.

INTRODUCTION / SCOPE BASIS

As operators find oil and gas reserves in deeper water, production risers become a critical component of field developments. Deepwater floating facilities take the form of semi-submersibles, tension leg platforms (TLP's), spars and floating production storage and offloading (FPSO) facilities. FPSO are being increasingly used world-wide and in recent years industry has developed a preference for external turret moored vessels as a means of improving FPSO construction schedules and reducing vessel costs.

The major types of deepwater risers are flexibles, Steel Catenary Risers (SCR) and HRTs. HRT's have been in service with spread moored FPSO vessels in West Africa since 2001 on the Girassol Project.

Besides being field proven, HRTs such as the Acergy Hybrid Riser Tower (Figure 1) offer specific advantages:

- Riser loads on the Floating Production Unit are reduced
- Field layout is robust, simplified, and allows all types of mooring systems and unforeseen future field expansion
- Large diameter risers can be accommodated
- Demanding flow assurance requirements can be met
- Flexibility of installation sequence for vessel, subsea flowlines and riser tower
- In place riser fatigue is minimized

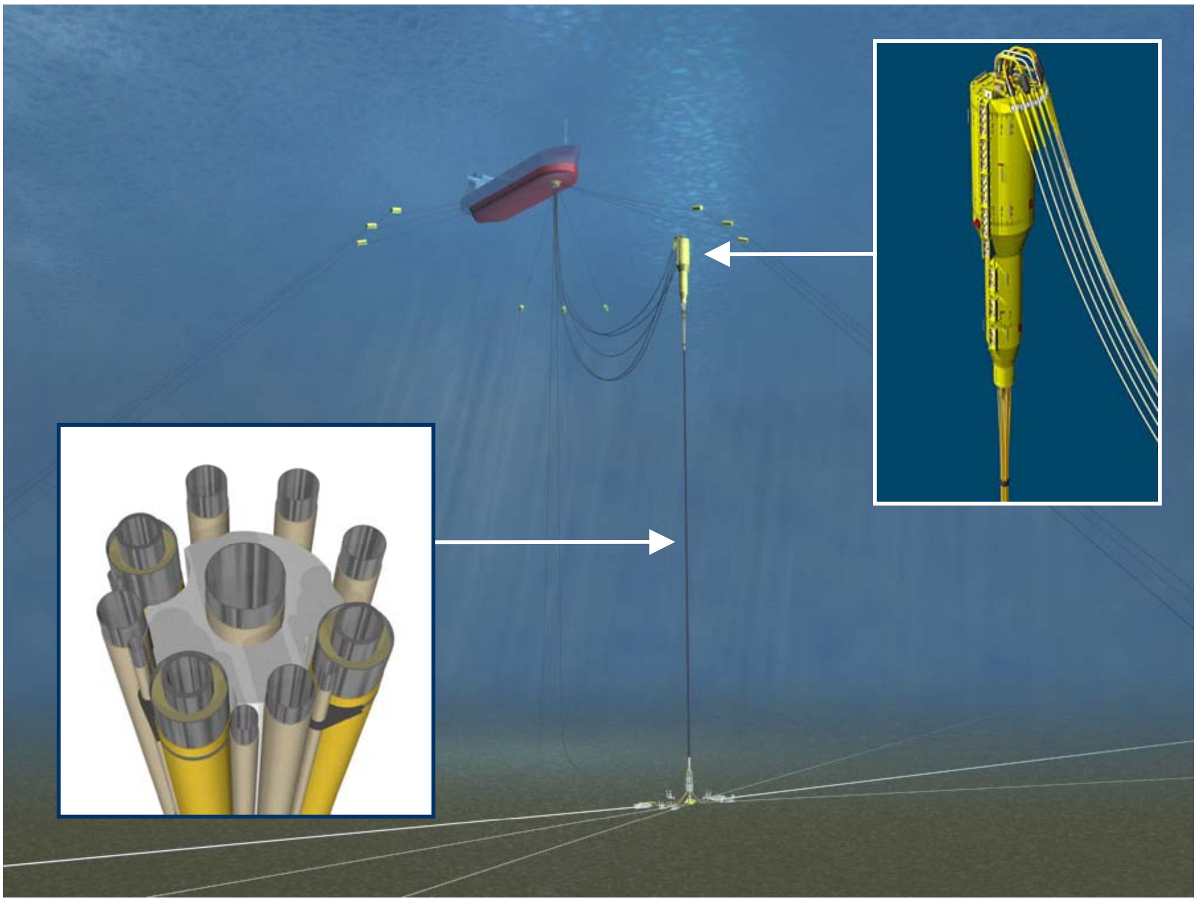


Figure 1: Acergy Hybrid Riser Tower System

The lower cost of an external turret FPSO in conjunction with the advantages of the HRT system offer significant cost savings for field development. At the same time, it is able to accommodate local extreme metocean conditions such as the Loop current in the Gulf of Mexico.

The HRT consists of a riser tower (riser bundle and submerged buoyancy tank) and flexible jumpers between the buoyancy tank and the FPSO (Figure 2). The jumpers hang in catenaries between the pivoting turret on the underside of the FPSO hull and the buoyancy tank that is between 50 and 250 m below sea level, depending on local metocean conditions.

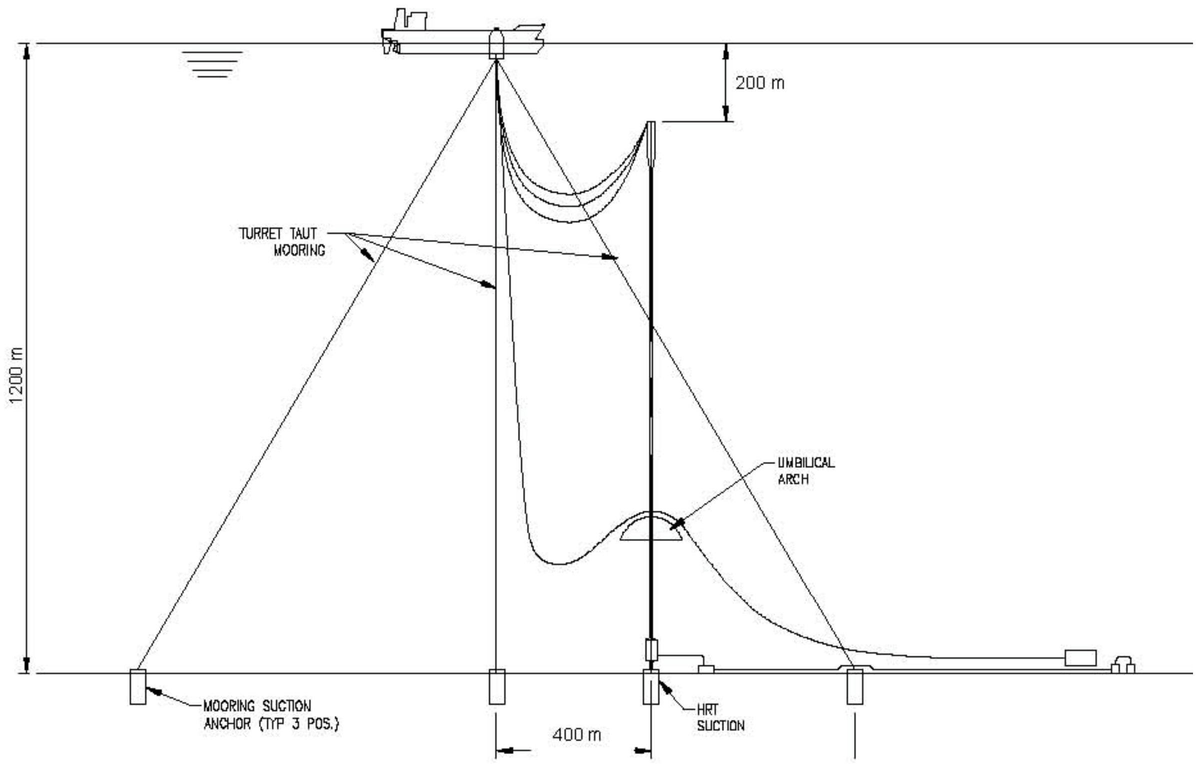


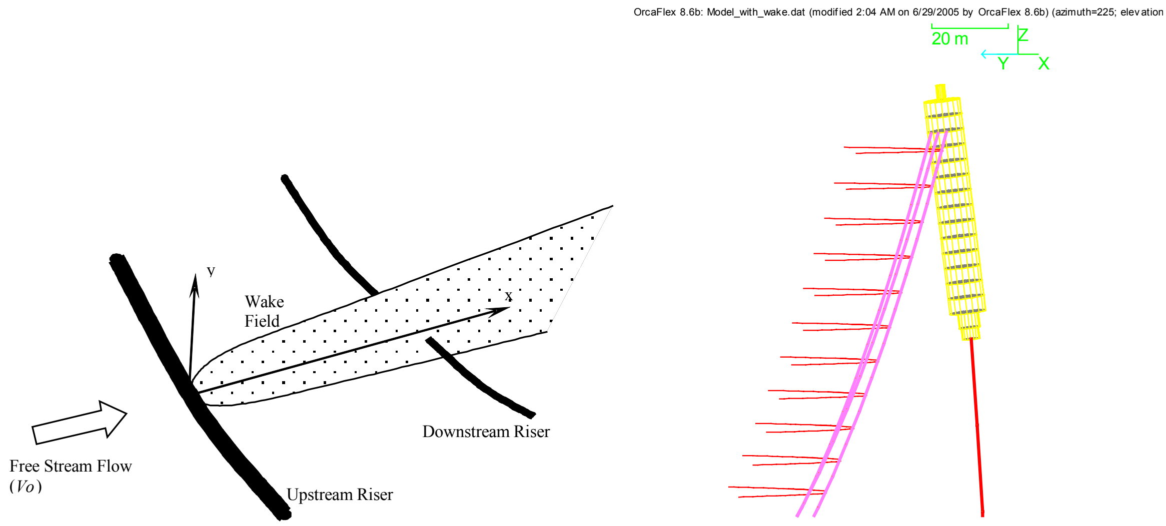
Figure 2: Typical HRT System Layout (Campos Basin, Offshore Brazil)

The close spacing of the jumpers at the turret leads to the possibility of jumper clashing under hydrodynamic loads. Consequently, two particular aspects of wake interference, wake shielding and wake instability, must be investigated.

The phenomena of wake instability and wake shielding arise when the wake from an upstream body affects the flow field around a downstream body. The significance of the effect on the down stream body, will, however, be dependent on the position of the body in the upstream wake. Thus, both wake shielding and instability assessments require definition of the downstream jumper geometry relative to the upstream jumper (Figure 3).

Since the local flow field varies with depth and direction and the jumpers are in a catenary configuration, interference can only occur on part of the downstream jumper. The relative positions of the jumpers were calculated using a search algorithm that first identified the positions on the downstream jumper that intercepted the wake plane associated with an upstream jumper segment. These intercept points were then transformed into a co-ordinate system with origin at the upstream riser segment. A logic test can then performed to determine whether the downstream intercept lay within a calculated wake boundary. Shielding and instability assessments are only carried out for intercept points lying respectively within the wake boundary and the critical domain for wake instability (see Ref. [1]).

A study was therefore carried out to assess jumper interference for the HRT for metocean conditions in the Gulf of Mexico and Offshore Brazil. Methods to account for wake shielding in the calculation of the extreme conditions, and criteria for the possible occurrence of wake instability were developed as part of this study.



Visualization in of Wave Profile in Orcaflex

Figure 3: Wake Field Co-ordinate System

HRT SYSTEM CONFIGURATION

The HRT primarily consists of a free standing riser tower that is comprised of a riser bundle, a buoyancy tank, and flexible jumpers between the buoyancy tank and an FPSO (Figures 1 and 2).

The riser bundle is attached to an articulated base (with a flex joint) that is, in turn, anchored to the seabed by a suction caisson. The core of the bundle consists of a steel pipe that is surrounded by syntactic foam buoyancy. Steel risers are located on the outer perimeter of the foam buoyancy (i.e., the bundle may not be a smooth cylinder). The core of the bundle is connected to the buoyancy tank by a taper stress joint.

The buoyancy tank supports the riser bundle and jumpers. The HRT configuration evaluated in this study placed the top of the buoyancy tank, at a sufficient depth below mean water level to mitigate surface current effects (e.g. Loop Current effects in the Gulf of Mexico). The main body of the buoyancy tank had a nominal diameter of 9.5 m and the tank was assembled in 4-m sections. The top of the buoyancy tank supports gooseneck connections for each line and porches for the jumpers.

A configuration with twelve jumpers was selected for the investigation. The twelve jumpers consist of six 10-inch production lines with 65 mm of GSPU (Glass Syntactic Polyurethane) wet insulation, two 10-inch water injection lines, one 8-inch water injection line, one 8-inch gas injection line and two 6-inch gas lift bundles. The jumpers were draped in three separate groups between the FPSO and the HRT buoyancy tank

All production lines were carefully selected to be located in the forward part of the turret. The gas injection/lift lines, water injection lines and umbilicals were positioned in the aft of the turret. The umbilicals were interspersed between the lines in the aft section of the turret. All jumper hang-off points were cautiously set on the 9.5-m diameter buoyancy tank. The corresponding hang-off points on the buoyancy unit were arranged in three layers (production on top, gas in the middle and water injection on the bottom) with radii of 7.25 m, 6.25 m and 5.25 m, respectively. The gas and water injection lines were grouped on either side of the buoyancy tank. The vertical spacing between the buoyancy unit hang off points was 4 m to match the height of one unit of the tank main body.

The hang-off points of the above-mentioned turret and buoyancy tank facilitate three jumper drapes with varying line lengths (Figure 4).

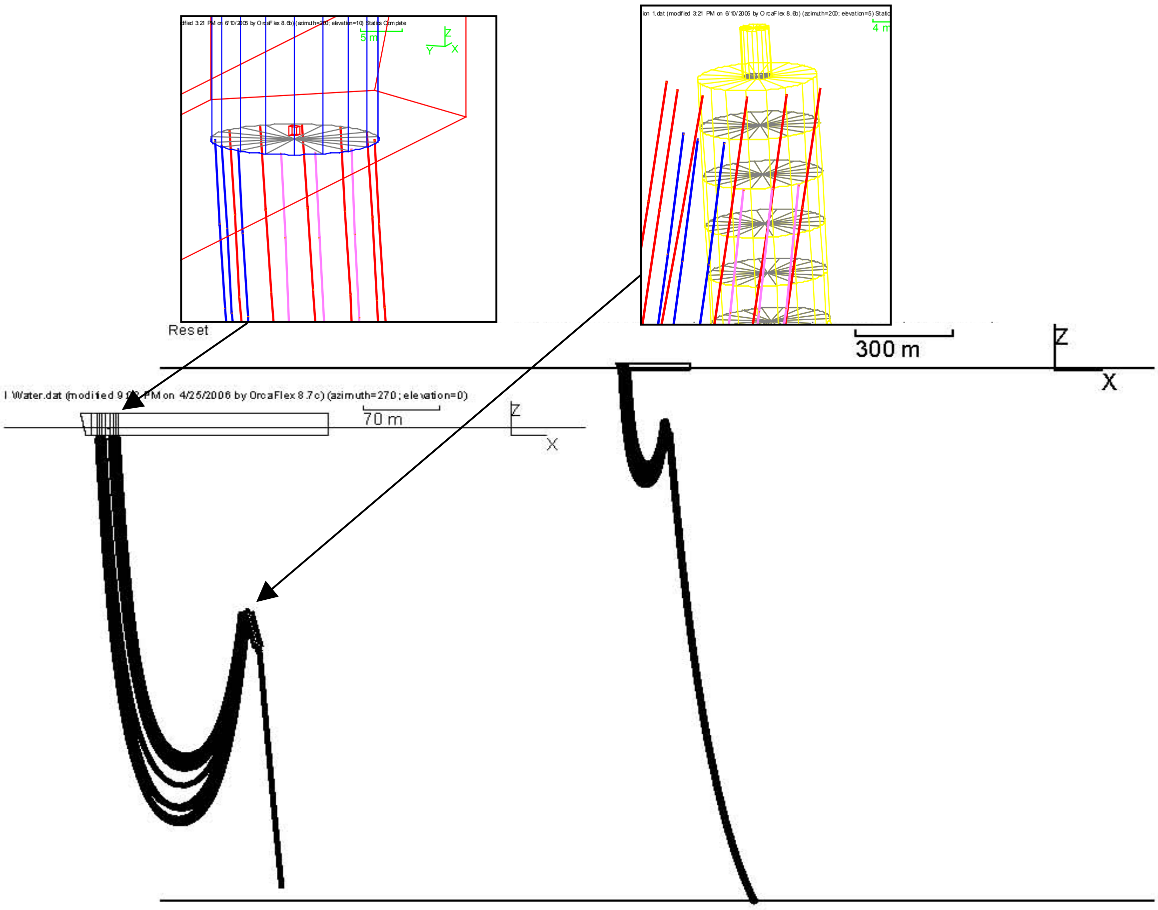


Figure 4: Example Jumper Hang off Positions

DESIGN ENVIRONMENT

Table 1 shows the representative extreme and operating environments for GOM and Brazil (Campos Basin) that were used in assessing the HRT system.

Design Condition	Gulf of Mexico(1)		Brazil (Campos Basin)(2)	
	Operational	Survival	1 Year	100 Year
Water Depth (m)	2500		1760	
Maximum Wave Height (m)	1.8	7.3	10.7	14.6
Period Associated with Max Wave (sec)	6.0	11.9	12.9	13.7
Vessel Offset (% WD)	8	10	6	8

(1) Hurricane condition not considered as turret assumed to be dis-connectable.
(2) Max Directional Heading from South West

Table 1: Representative Environments - Gulf of Mexico and Brazil (Campos Basin)

Figure 5 shows a comparison of the current profiles used for each site. Note that current was considered to be collinear and non-collinear with the wave environment from different headings.

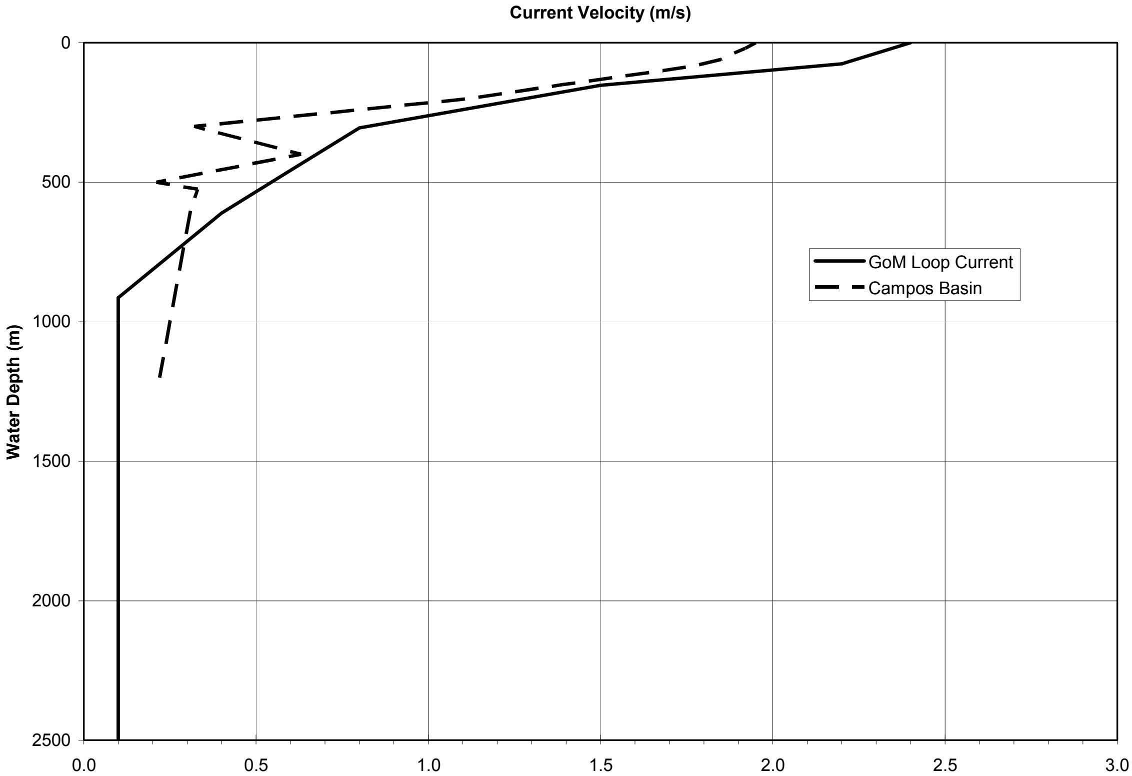


Figure 5: Representative Current Profiles - Gulf of Mexico and Brazil (Campos Basin)

JUMPER INTERFERENCE METHODOLOGY

Appendix I shows a flow chart of the assessment procedure for wake shielding and wake instability.

Initial iterations were performed on the HTR system to obtain a jumper configuration that has still water clearances of not less than five (5) average diameters between any two jumpers (centerline to centerline).

The second step in the procedure is a wake shielding analysis considering the effects of mean vessel offset and current profile. Analyses are based on a wake deficit model in quasi-static conditions, Ref [1]. OrcaFlex is used to calculate the static system configuration of the jumpers due to the applied loads. A customized spreadsheet calculation then uses the OrcaFlex static configuration to determine the interaction between jumper pairs and the reduction in local downstream loads (in the form of modified drag factors) due to wake shielding. The modified drag factors are then used in OrcaFlex to determine an updated system static configuration.

Successive iterations are performed for each case until a converged static state is achieved.

Wake shielding calculations are performed for selected headings considering in line current and opposing vessel offset. The two environmental conditions represent the potential for vessel offset to be dominated by wind. The jumper loads are dominated by currents. As with the still water conditions, iterations are performed to obtain a system that meets a minimum clearance specification. The desired minimum clearance for quasi-static conditions is two (2) diameters.

The third step in the procedure is dynamic analysis to determine the potential for wake instability due to mean vessel offset, current and wave loads.

The wake instability calculations are divided into two parts. The first is an interaction analysis that is carried out in OrcaFlex and supporting customized spreadsheets. These calculations are used to identify individual jumper pairs where a downstream jumper lies inside the wake of an upstream jumper. The second portion of the analysis is carried out using MathCAD/Mathematica to identify the dynamic interaction of the jumper pairs, Ref [1].

The duration of the OrcaFlex analyses are of the order of twenty (20) regular wave cycles to allow the HRT system to obtain a steady state response. This duration is longer than typically required for a riser system and is attributed to the system compliance. Steady state conditions are then interrogated using the customized spreadsheets to determine whether downstream jumpers line inside or outside of an upstream jumper wake. This interrogation is performed ten (10) times within the last regular wave cycle to identify if a downstream jumper moves in and out or is permanently located in the of the upstream jumper wake during a regular wave period. The desired minimum clearance for dynamic conditions is one (1) diameter.

SAMPLE RESULTS

Wake Shielding Assessment (Static Analysis)

Typical results for jumper clearance before and after wake shielding calculations are shown in Figure 6. While these results are specific for Gulf of Mexico Loop Current conditions, they are also indicative of the results obtained for Campos Basin conditions. In the cases shown, shielding occurs along most of the jumper lengths which result in a reduction in clearance in a majority of the cases. However, the change in configuration due to shielding can also result in increased in-line clearance.

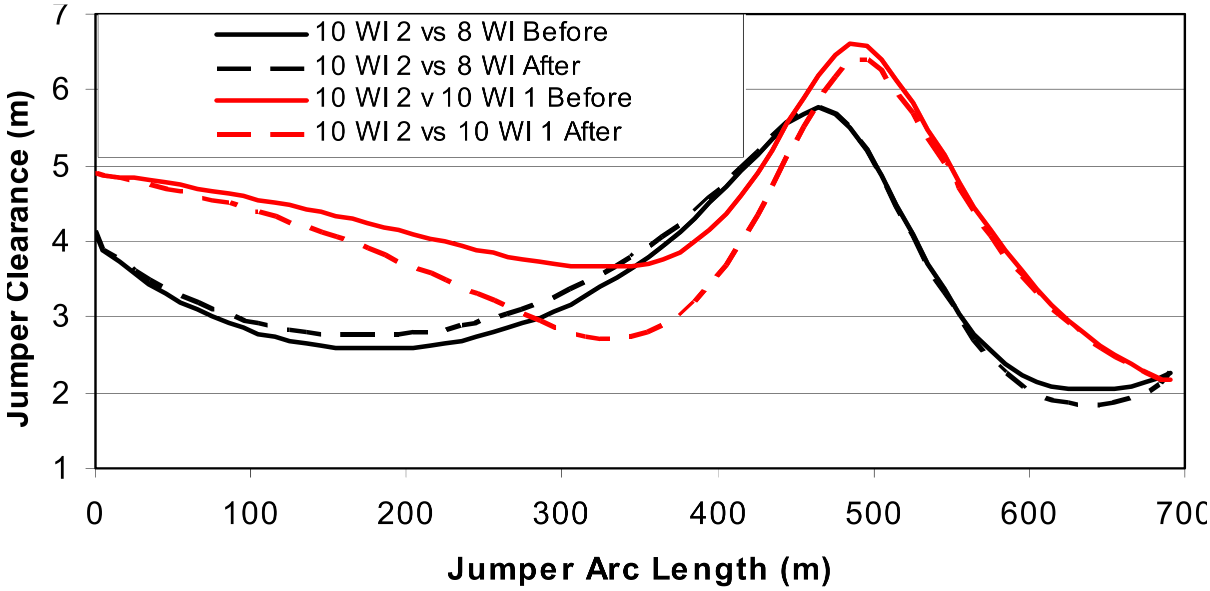


Figure 6: Sample Results for line clearance from Static Wake Shielding Calculation

The results of the shielding analysis indicated that there were only six cases that developed line clearances of less then two diameters. Out of these six, only one case resulted in a line clashing condition. In this specific case, adjusting the downstream jumper length (reduction in length of up to 10 m) eliminated this condition.

Similar results were observed for the HRT assessment in Brazil (Campos Basin) conditions.

Wake Instability Assessment (Dynamic Analysis)

Dynamic jumper response was assessed for eight environmental headings at both sites. Only a limited number of jumper interactions (less than 10 out of a possible 132 at each site) resulted in clearances that could cause potential wake instability. This was attributed to the pre-screening of the jumper configurations in still water and under static current loads (including wake shielding) which was used to eliminate the majority of interference cases. All cases in the Campos Basin conditions and all but one case in Gulf of Mexico conditions occurred in the first 200 m of jumper arc length from the turret. It was noted that the majority of cases that required further investigation were associated with the gas lines. This was attributed to the lighter cross-section, which resulted in relatively larger excitation for vessel and environmental loads.

Figure 7 shows a typical clearance case between two gas jumpers from the Campos Basin case. Minimum clearance is over a short arc length between 170 m and 190 m from the FPSO end. Further interrogation of the downstream jumper indicated that it traversed the upstream jumper wake approximately 1 m downstream for the upstream jumper (Figure 7, Table 2).

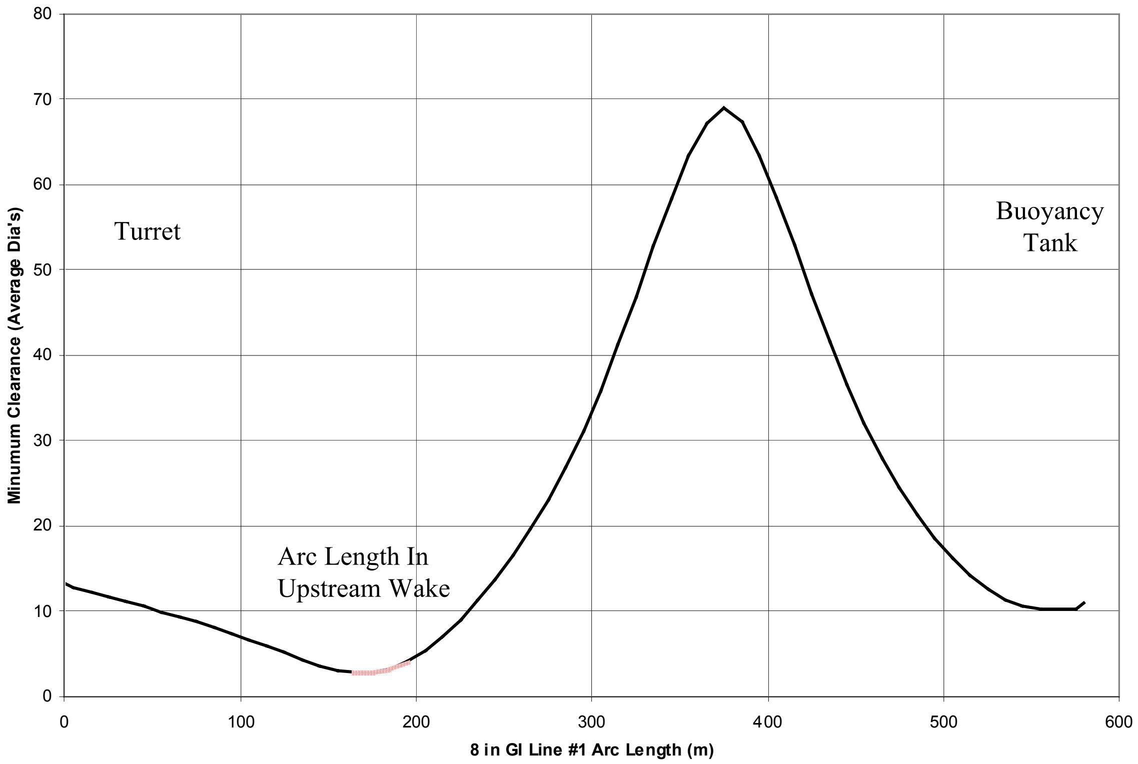


Figure 7: Minimum Clearance Between Upstream 8" GI Line #1 and Downstream 6" GL Bundle #2 (Campos Basin - Environment from Northeast)

Upstream Jumper Arc Length (m)	Max Current (m/s)	Min Current (m/s)	Downstream Jumper Wake Position			
			X Min (m)	X Max (m)	Y Min (m)	Y Max (m)
170	1.34	1.23	0.70	0.80	-0.29	-0.19
180			0.92	1.03	0.01	0.10
190			1.18	1.29	0.33	0.42

Table 2: Interaction Between Upstream 8" GI Line #1 and Downstream 6" GL Bundle #2 (Campos Basin - Environment from Northeast)

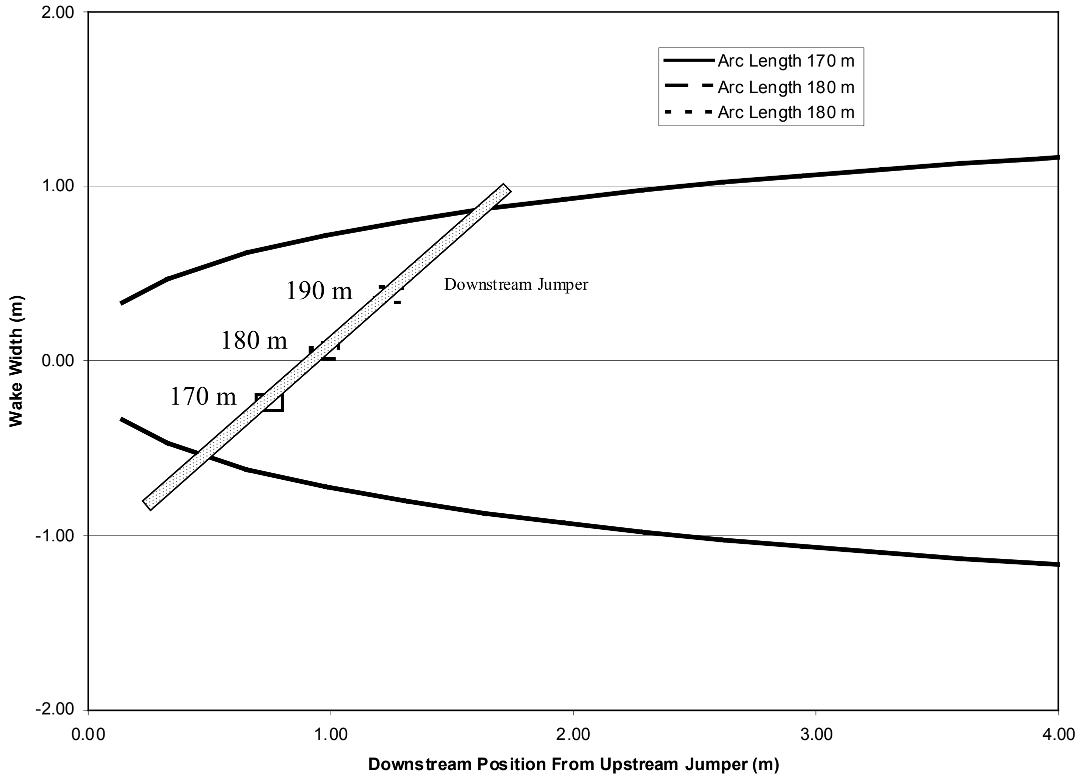


Figure 8: Wake Intercept Points of Upstream 8” GI Line #1 and Downstream 6” GL Bundle #2 (Brazil (Campos Basin) - Environment from Northeast)

Figure 9 shows the line clearance between gas lines of the case with interaction over the middle of the jumper arc lengths. Approximately 100 m of arc length lies in the downstream wake. However, this is offset by the low local free-stream current, which significantly reduces the potential for wake instability. Table 3 gives the co-ordinates of the downstream jumper in the upstream jumper wake.

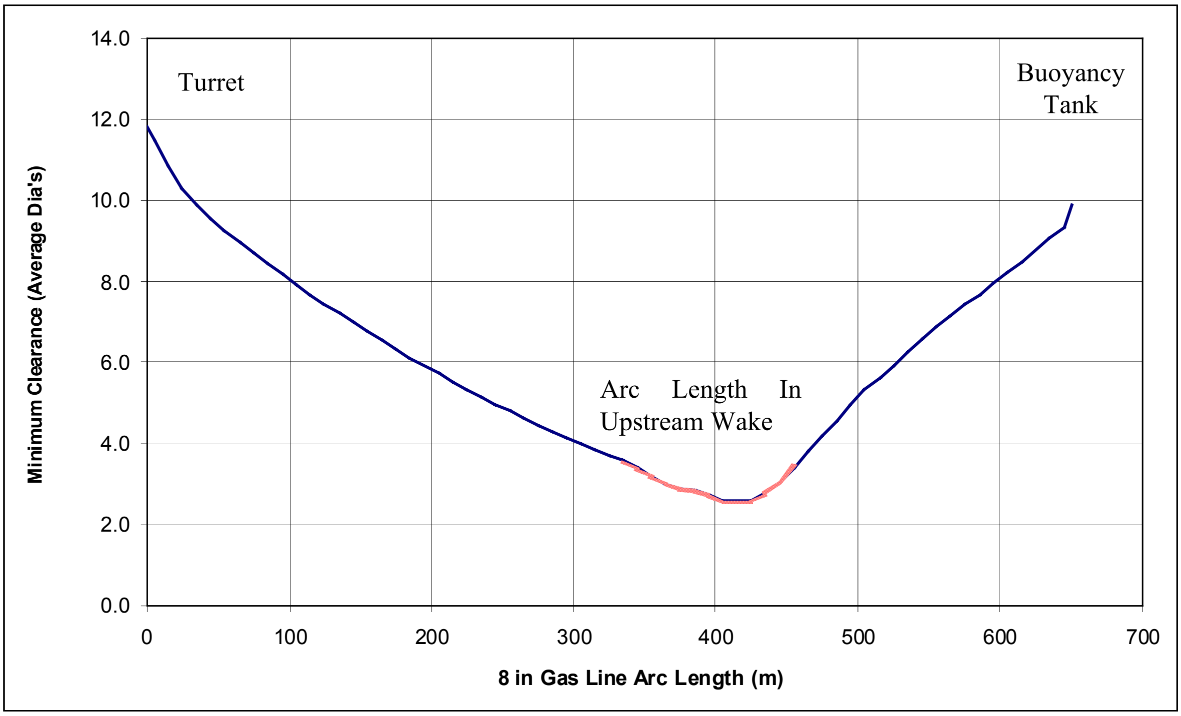


Figure 9: Minimum Clearance Interaction Between Upstream 8" GL Line #1 and Downstream 6" GL #2 (Gulf of Mexico - Cross Condition)

Upstream Jumper Arc Length (m)	Max Current (m/s)	Min Current (m/s)	Downstream Jumper Wake Position			
			X Min (m)	X Max (m)	Y Min (m)	Y Max (m)
335	0.2	0.2	1.53	1.07	-0.53	-0.65
345			1.46	1.06	-0.45	-0.58
355			1.38	1.06	-0.37	-0.53
365			1.29	1.04	-0.28	-0.47
375			1.20	1.03	-0.19	-0.42
385			1.11	1.02	-0.09	-0.35
395			1.07	1.01	0.01	-0.28
405			1.06	0.98	0.12	-0.20
415			1.07	0.94	0.24	-0.11
425			1.09	0.94	0.37	-0.03
435			1.09	0.94	0.37	-0.03
445			1.10	0.95	0.50	0.07
455			1.13	0.97	0.63	0.17
335			1.15	1.01	0.78	0.28

Table 3: Interaction Between Upstream 8" GI Line #1 and Downstream 6" GL #2 (Gulf of Mexico Cross Condition)

Two Dimensional Wake Instability Assessment

Wake instability is identified as a matter of significance by DNV-RP-F03, and indeed has been studied in detail by Blevins, Ref [2], and Fontaine et al., Ref [7].

Whereas wake shielding addresses the effect of drag only on two adjacent cylinders, wake instability may be looked at as resulting from the effect for both lift and drag.

In Blevins et al., Ref [1] has shown that the effect of wake instability may be limited to a domain defined by a criterion depending on the free stream velocity, the mass and the frequency of the transverse mode of the downstream jumper.

This allows the interference analysis to be conducted in steps: First, using Orcaflex as described above, the wake shielding, and for the cases that fall into the instability domain, a more specific two-dimensional wake instability analysis.

When analyzing the results of wake shielding, it may be found that the downstream jumper may fall into the domain of wake instability either at each end or in the middle. For jumpers the stiffness at each end can be adjusted to eliminate the issue, and therefore the most critical case to solve is when jumper interference is found in the middle of the line.

Its must be noted that the velocity of the current is in the horizontal plane and that jumpers roughly follow the same path. Therefore, when interference occurs in the center of the riser or jumper, the modes of interest are the transverse mode in the direction of the current, and the first inline mode in the direction perpendicular to the current.

The equation of motion mentioned in Ref [1] are valid for cases where the downstream line is in the wake of the upstream line along its entire path. These equations have been modified to account for the actual exposure. Limiting the exposure can be achieved by setting the lines at slightly different lengths. Small change in length can dramatically modify the exposure.

For the cases, which have been identified by the wake shielding analysis as falling into the wake instability criteria, a specific 2D model is built. The model uses input of the initial position at rest for the upstream and downstream jumpers. The current velocity is increased from 0 to the design value.

Two cases were found of concern both involving the gas lift (GL) and gas injection (GI) lines. It may be noted that no cases were found for the heavier production and water injection jumper lines.

In both cases it was found that the impact of wake instability was negligible, thereby validating the design.

Vortex induced vibrations (VIV) of the upstream jumper was not specifically addressed in this analysis because the selection value of the drag coefficient. It can be observed that the drag coefficient and the diameter always appear combined. Increasing the drag coefficient can be considered as compensating for the effect of VIV of the upstream jumpers.

The actual indications, in terms of the Reynolds number, are those of super critical regime. Nevertheless, drag coefficient typical of sub-critical regime, are conservatively selected.

Figure 10 shows the plot of jumper movements and the critical curve for wake interaction for an 8-inch upstream jumper and 6-inch downstream jumper at an initial specific position. The critical curve provides a boundary for the occurrence of wake instability.

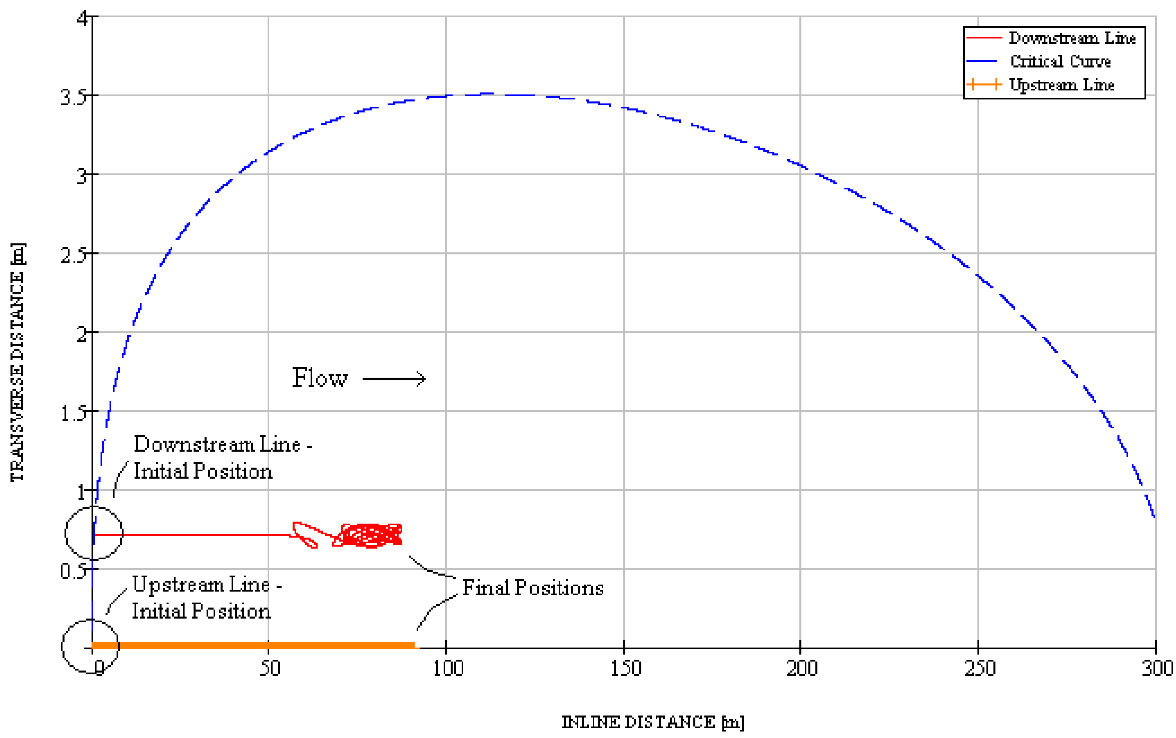


Fig 10: 2D model for wake instability (Dynamic Response)

COMPARISON OF HRT CONFIGURATIONS FOR GOM AND BRAZIL

Table 4 shows the primary differences between the HRT configurations for Gulf of Mexico and Campos Basin conditions. The FPSO and turret were kept the same for study purposes. The riser length and buoyancy tank size were governed by water depth and surface environment conditions. Variations in jumper lengths were controlled by vessel offset and by spacing requirements to mitigate wake interference.

		Gulf of Mexico	Campos Basin
Water Depth (m)		2500	1760
Riser Tower Length (m)		2183	1564
Riser Tower Diameter (m)		1.88	1.82
Offset – Turret ℄ & HRT Bottom(m)		500	400
Buoyancy Tank Diameter (m)		9.5	
Jumper Lengths (m)	Production #1	600	500
	Production #2	580	500
	Production #3	600	500
	Production #4	590	490
	Future Production #1	610	510
	Future Production #2	610	510
	10 in Water Injection #1	700	610
	10 in Water Injection #2	700	580
	8 in Water Injection #1	690	600
	6 in Gas #1	650	540
	6 in Gas #2	650	550
	8 in Gas #1	650	580

Table 4: Main Characteristics of HRT System

CONCLUSIONS

The close proximity of the jumper lines between the HRT and the FPSO turret makes the potential for jumper interference (shielding, instability and clashing) a critical issue for the concept of a combination of an HRT and a turret-moored FPSO. A full assessment of interference was carried out that included a methodology for the evaluation of wake shielding and wake instability.

The results of the jumper interference assessment confirmed the applicability of the Hybrid Riser Tower system with a turret-moored FPSO for both GOM and Brazil (Campos Basin) conditions.

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APPENDIX I: WAKE INTERFERENCE ASSESSMENT FLOWCHART