EXPERIMENTAL STUDY ON THE EFFECT OF THE CURRENT WAKE ON THE FPSO-SHUTTLE FISHTAILING DYNAMICS

Alexandre N. Simos[1]
(alesimos@usp.br)

Carlos H. Fucatu[1]
(chfucatu@usp.br)

André L.C. Fujarra[1]
(afujarra@usp.br)

Vinícius L.F. Matos[2]
(vmatos@petrobras.com.br)

1 - Department of Naval Architecture and Ocean Engineering
Escola Politécnica - University of São Paulo
São Paulo, SP, Brazil

2 – PETROBRAS – Exploration & Production
Rio de Janeiro, RJ, Brazil

ABSTRACT

Offloading operations of FPSO (Floating Production Storage and Offloading) systems are usually performed by means of a shuttle tanker connected by a hawser to the FPSO in a tandem configuration. Depending on the environmental condition and on the connection configuration, a dynamic instability can occur when the shuttle tanker undergoes a low frequency drift motion with large amplitude known as fishtailing.

The mechanics of the fishtailing phenomenon is similar to that of a pendulum, the restoring force being played in this case by the longitudinal force on the shuttle tanker. The hydrodynamic current forces play an important role in the fishtailing problem, thus it is expected that the wake generated by FPSO will have a great influence in the shuttle behavior.

This paper presents a set of new tank tests results, performed in NMRI Japan, showing the influence of the hydrodynamic interaction between the two small-scale tanker models in tandem configuration. These tests are part of an extensive program that aims the development and validation of a suitable procedure for estimating wake effects along time domain simulations.

1. INTRODUCTION

Offloading operations of FPSO (Floating Production Storage and Offloading) systems are usually performed by means of a shuttle tanker which receives the oil pumped by the FPSO. The shuttle is connected to the FPSO by a hawser, such connection being made, in many cases, either at the stern or at the bow of the platform. The two ships are thus connected in tandem and the dynamics of the two floating bodies under wave, current and wind action may present a very rich behavior (see, for example, Faltinsen et al. (1979) and Simos et al. (2001)).

Figure 1. FPSO offloading operation

Depending on the connection configuration (hawser length and connection position at the shuttle tanker) and the combination of the environmental forces, the system may present an unstable dynamic behavior known as "fishtailing". In this situation, the shuttle tanker undergoes an oscillatory motion with amplitudes that can be high enough to pose a threat to the safety of the operation. In practice, this problem is avoided by "pulling" the shuttle tanker away of the FPSO either by the assistance of a tug boat or using the shuttle dynamic positioning system (DPS), if the ship is equipped with one.

Current forces play an important role in the fishtailing problem and they depend on the flow that effectively reaches the shuttle hull. One of the main difficulties in modeling these forces is that this flow is disturbed by the FPSO hull and the viscous wake may present significant effects concerning the amplitude and direction of such forces. This is especially true when the current reaches the FPSO with a somewhat large angle of incidence, situation common, for example, for FPSOs moored by means of spread mooring systems (SMS). However, angles up to 30 degrees may also happen for FPSOs in turret configuration, depending on the combination of waves, current and wind action.

Determining the environmental criteria under which offloading operation of a particular unit is acceptable is an important task and to a great extent depends on systematic dynamic evaluations of the system based on the statistical environmental data of the field. The role of dynamic simulation packages in this study is crucial, not only because it allows evaluating any possible combination of waves, wind and current conditions, but especially for the reason that the fishtailing phenomenon in full scale cannot be directly extrapolated from model tests. This is a central issue concerning the present research and will be explained in details in the next section.

The Numerical Offshore Tank (NOT) at the University of São Paulo (USP) is a simulation package with very large numerical processing capability, allowing for the analysis of full scale offshore units with coupled dynamics of risers and mooring lines. The NOT is the only simulator that includes the time variation of wave interaction effects for multi-body systems[1]. However, like the majority of the commercial packages, it does not take into consideration the wake effects on current and wind loads.

Since 2006, a research projected supported by Petrobras has been conducted at USP for determining a suitable approach for modeling such viscous wake effects. In a previous study, Fucatu et al (2001, 2003 and 2004) showed through model tests the wake influence in the shuttle behavior and presented a tentative numerical model based in velocity field calculated by CFD programs. Despite the good results, the proposed approach was not practical due to excessive time demanding to data preparation. Now, both semi-empirical and numerical (CFD) models are under evaluation and may be merged for performing such task.

The research is supported by an extensive model test campaign conducted at the National Maritime Research Institute (NMRI) in Japan, which set an important experimental basis for calibration and validation of the hydrodynamic model pursued. This paper focus on the so-called free-running tests (in which two small-scale models are connected by means of a rigid hawser) and on the experimental evidence of the important role played by current wake effects on the fishtailing dynamics.

[1] This is possible since a BEM seakeeping code (WAMIT®) is coupled to the NOT, allowing for correcting the ships relative positions and, therefore, the wave induced drift forces (see Tannuri et al. (2004)).

2. THE FISHTAILING PHENOMENON - SCALE EFFECTS

The study of the fishtailing phenomenon has been extensively reported in literature, examples been given by Faltinsen et al. (1979), Wichers (1987) and Tannuri et al. (2001). This last work, in particular, points to the important issue of scale effects on the extrapolation of tank data. This is a central issue and will be briefly discussed in this section.

Let's consider a ship model in a Single Point Mooring (SPM) configuration, which is towed at the tank with constant velocity *U*, as illustrated below.

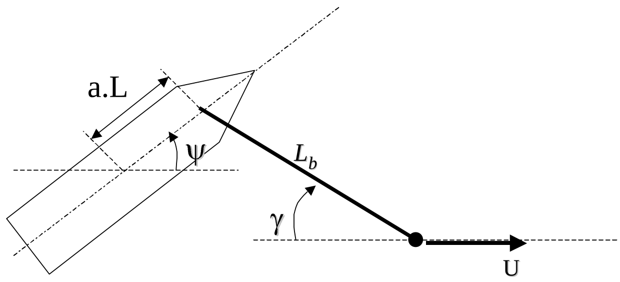

Figure 2. Skecth of a ship in SPM configuration.

L_b represents the hawser length and L the model length. If the hawser is considered to be rigid, then the model motion can be expressed only by the model heading and hawser angle, given respectively by ψ and γ.

Along the fishtailing motion the heading angle remains small, typically below 20 degrees. This means that the current forces are indeed dominated by the model resistance. Also, since one is dealing with small velocities, the Froude number is small, usually below 0.1. The model resistance is, therefore, dominated by the frictional component on the hull and it is reasonable to approximate this force by the usual ITTC line with a standard form factor:

$$F_{X,R} = \frac{1}{2}\rho U^2 LT \cdot C_F(\text{Re});$$

where:

$$C_F(\text{Re}) = \frac{0.075}{(\log_{10}\text{Re} - 2)^2} \cdot \frac{S}{TL}(1+k)$$

S being the model wetted surface, and T the model draft. For oil tankers, a typical value of the Prohaska factor is (1+k) = 1.25 (see, for example, van Manem and van Oossanen (1988)).

The fishtailing dynamics is then very similar to that of a pendulum, the restoring force now being played by the friction resistance. Due to the dependence of the restoring force on the Reynolds number (Re), however, it is easy to realize that the fishtailing dynamic behavior is not independent on the scale reduction. For example, a typical scale factor adopted in the towing tank for a VLCC hull model is 1:100. In this case, the real scale friction coefficient is typically 3 times lower than in model scale. Hydrodynamic restoring forces in full scale are thus proportionally lower. In conclusion, if the model undergoes fishtailing in the tank, in the same conditions the real scale tanker would experience a stronger instability, with larger angles.

In conclusion, it is important to stress that the fishtailing dynamics cannot be directly evaluated from small-scale tests. For evaluating the real scale dynamics, one needs to make use of a tool that correctly incorporates the scale effects discussed above. As a consequence, time-domain simulators represent an indispensable choice for evaluating offloading operations in different environmental scenarios.

Towing tank tests, however, are also indispensable for the validation of the hydrodynamic models implemented in the simulator code. This is especially true if the model shall cope with viscous wake effects when dealing with an FPSO and a shuttle tanker in tandem. For this reason, several free-running tests were conducted at the NMRI and will be discussed next.

3. MODEL TEST

In order to evaluate the wake effect three different model tests were carried out.

a) Disturbed velocity field mapping – The current velocity in FPSO downstream was measured in several points in order to have a map.

b) Two ships captive towing test – FPSO and shuttle were towed in several relative position and the forces acting in shuttle was measured.

c) Free running towing test – The FPSO was towed in a fixed angle and the shuttle was connected to it through a rigid riser.

In this paper it is presented only the free running tests results.

The FPSO and shuttle ship models were identical and the main particulars are presented in Table 1.

Parameter	Model scale
Length	3.00m
Breadth	0.544m
Draft	0.181m

Table 1: Models main particulars.

3.1 Free Running Test

A series of free-running tests was performed, varying the towing velocity, the FPSO heading, the draft of the models and the hawser length. A rigid hawser was employed to connect the models in order to reduce transient responses; this approach has been used before (Tannuri et al. (2001)) and it makes it easier to reach the steady state along the tank.

Tests were carried out at the middle towing tank (L150m×B7.5m) of the National Maritime Research Institute in Tokyo, Japan.

The shuttle motion was captured through a video tracker system. Figure 3 and 4 show a sketch and a picture of the test.

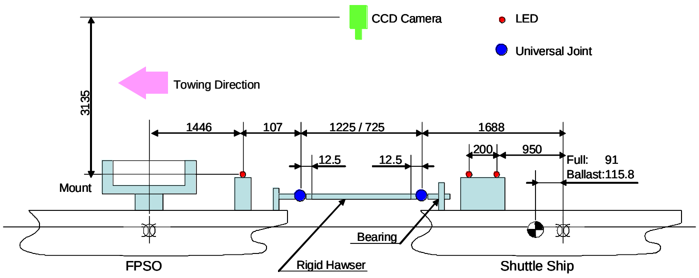

Figure 3: Test sketch

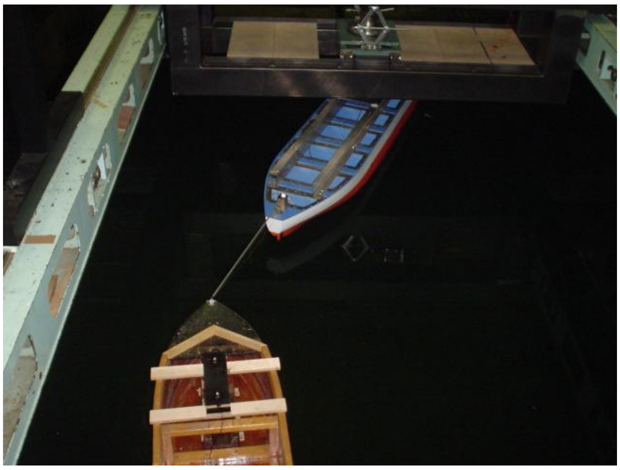

Figure 4: Test set up

The tested parameters were:

a) Hawser length:
0.7 and 1.2m

b) Draft combinations :
FPSO 100% with shuttle 40%

FPSO 70% with shuttle 100%

c) Current velocity
0.2 and 0.3m/s

d) FPSO heading angle :
0, 22.5 and 35 degrees

3.2 Results

Among the 58 performed tests just few cases were picked up to illustrate the wake effect. Figures 5 to 9 show time series of the shuttle ship motion for the following condition:

- Hawser length: 0.7m
- Draft combination: FPSO 100% / shuttle 40%
- Current velocity: 0.3m/s

In the graphs, the surge, sway and yaw motions respectively are represented by the lines blue, magenta and green.

Figure 5 shows the case without the FPSO in upstream position. The Figures 6 and 7 show the case with FPSO in upstream with 0 degree of heading angle.

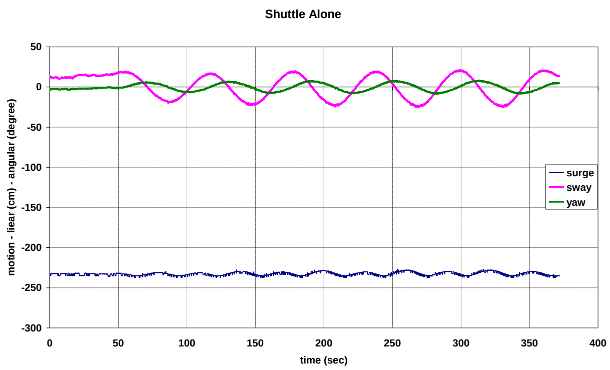

Figure 5: Shuttle motion – without FPSO

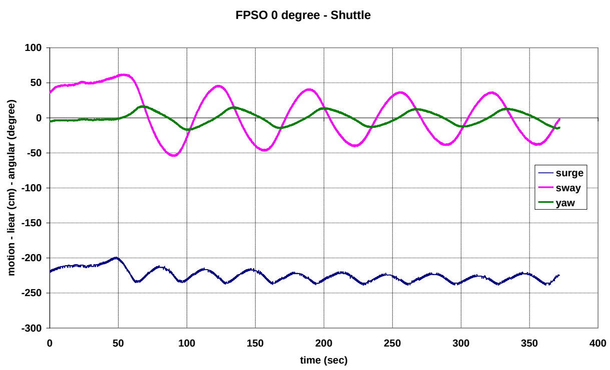

Figure 6: Shuttle motion –FPSO 0 degree

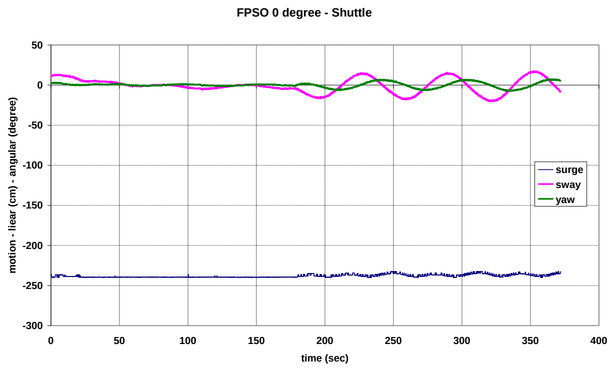

Figure 7: Shuttle motion –FPSO 0 degree

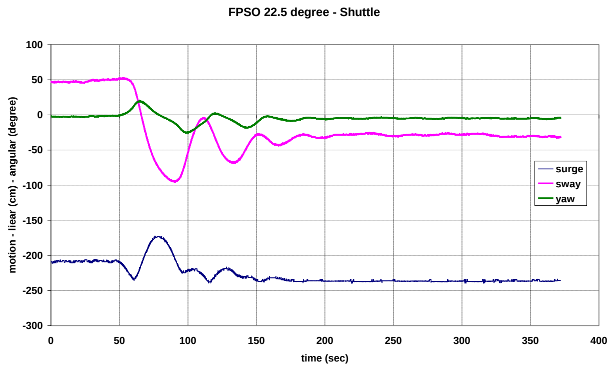

Figure 8: Shuttle motion –FPSO 22.5 degree

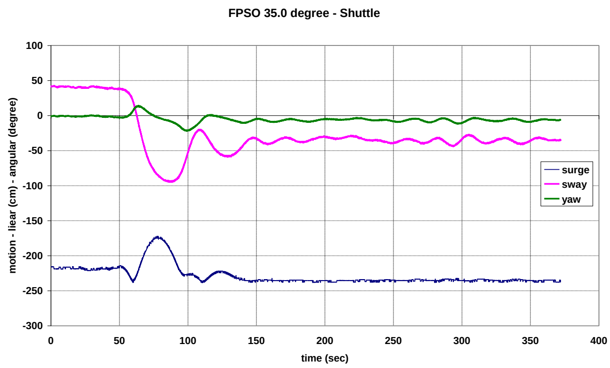

Figure 9: Shuttle motion –FPSO 35.0 degree

In Figure 6 an initial displacement was imposed and the shuttle performs a classical fishtailing motion with constant amplitude. It can be noted that FPSO wake makes shuttle perform a sway motion with broader amplitude when compared to the case without FPSO.

On the other hand, in Figure 7 the initial position of shuttle is right behind FPSO. In this case the shuttle stays in a static equilibrium until an external force is applied. After that fishtailing arise with increasing amplitude. In “shuttle only” case this behavior was not observed.

The Figures 8 and 9 show the case with FPSO in upstream with 22.5 and 35 degree of heading angle respectively. Here the wake effect is strong enough to kill the fishtailing and lead the shuttle to a static equilibrium.

The same behavior could be observed to the longer hawser and low velocities cases. For the inverse draft combination, FPSO 40% / shuttle 70%, not all the presented a clear wake effect.

4. CONCLUSION

A discussion on the hydrodynamic interaction effects on the dynamics shuttle tankers during FPSO offloading operations was presented and illustrated by means of towing tank experimental results.

The results confirm that wake effects cannot be disregarded when modeling the offloading dynamics and the set of experimental results provide a good basis for the validation of the hydrodynamic (numerical or semi-empirical) current force models. In particular, they show that the influence of the wake may be large, in some cases even large enough to make the fishtailing oscillations stop, leading to a different static behavior. For typical current velocities and hawser lengths, an incidence angle above 20 degrees was enough for the oscillations to cease. This is indeed a common situation both for SMS and turret FPSO systems, depending on the combination of environmental forces.

The influence of current velocity, draft and distance between the two models could also be evaluated.

The experimental campaign conducted at the NMRI supports the calibration and validation of the interference effects models under development. Only by means of a validated time-domain simulator, the wake effects on real-scale offloading operations may be properly evaluated.

Acknowledgments

This work has been supported by Petrobras, by means of a research project with the University of São Paulo.

5. REFERENCES

Faltinsen,O.M. & Kjaerland,O. & Liapis,N. & Walderhaug,H (1979): "Hydrodynamic analysis of tankers at single-point-mooring systems". *Proceedings of the 2nd International Conference on Behavior of Off-Shore Structures*, BOSS´79, pp. 177-205;

Fucatu, C.H.; Nishimoto, K; Maeda, H.; Maseti, I.Q (2001): "The Shadow Effect on the Dynamics of a Shuttle Tanker"; OMAE-2001.

Fucatu, C.H.; Nishimoto, K (2003): "The Shadow Effect on the Dynamics of a Shuttle Tanker Connected in Tandem with a FPSO"; OMAE-2003.

Fucatu, C.H.; Nishimoto, K (2004): "An Empirical Model of Current Shadow Effect"; OMAE-2004.

Jiang,T. & Sharma, S.D. (1993): "Maneuvering simulation of a single-point moored tanker in deep and shallow water", *Proceedings of the Inter. Conf. on Marine Simulation and Ship Maneuverability*, MARSIM´93, pp. 229-241;

Leite,A.J.P. & Aranha,J.A.P. & Umeda,C. & de Conti,M.B. (1998): "Current forces in tankers and bifurcation of equilibrium of turret systems: hydrodynamic model and experiments", *Applied Ocean Research* 20, pp.145-156;

Simos, A.N., Tannuri, E.A., Pesce, C.P., Aranha, J.A.P. (2001): "A Quasi-Explicit Hydrodynamic Model for the Dynamic Analysis of a Moored FPSO under Current Action", Journal of Ship Research, Vol. 45, nr. 4, 2001, 289-301;

Tannuri, E.A., Simos, A.N., Leite, A.J.P., Aranha, J.A.P. (2001): "Experimental Validation of a Quasi-Explicit Hydrodynamic Model: Fishtailing Instability of a Single-Point Moored Tanker in Rigid-Hawser Configuration" Journal of Ship Research, Vol. 45, nr. 4, 2001, 302-314;

Tannuri, E.A., Bravin, T., Simos, A.N., Alves, K.H., Nishimoto, K. & Ferreira, M.D (2004). "Dynamic simulation of offloading operation considering wave interaction between vessels". Proc. 23rd Int. Conf. on Offshore Mech. And Arctic Eng. OMAE04, Vancouver, Canada, paper OFT-5118.

Wichers, J.E.W. (1987): "The Prediction of the Behavior of Single Point Moored Tankers", *Developments in Marine Technology*, Vol 4, Floating Structures and Offshore Operations, pp.125-142.