Available online at www.sciencedirect.com

SCIENCE DIRECT®

ELSEVIER Applied Mathematics and Computation 164 (2005) 649–665

APPLIED MATHEMATICS AND COMPUTATION

www.elsevier.com/locate/amc

Nonlinear dynamics of an archetypal model of ships motions in tandem

Jessé Rebello de Souza Jr. *, Claudio Gomes Fernandes

Department of Naval Architecture and Ocean Engineering, University of São Paulo, Av. Prof. Melo de Morais, 2231, Cidade Universitária, São Paulo 05508-030, Brazil

Abstract

Large converted tankers operate as floating platforms for the production of oil in offshore fields whose depth approaches 2000 m. Their dynamics are influenced by wind, currents, and waves, and also by the physical characteristics of mooring lines. In addition to the single-vessel operation mode, a two-ship tandem arrangement is employed during the transfer of cargo (offloading) from the main production vessel to a shuttle vessel that takes the oil to other processing plants. It is essential to design the system in a way that ensures that the dynamical behavior of the vessels during offloading is safe. Mathematical models that represent the motions of moored ships in the sea can be complex, particularly when detailed modeling of hydro- and aerodynamic effects is required. In this work a simplified (archetypal) model is developed and explored that includes wind and current effects, and the elastic interaction between vessels. The model is validated against time series and bifurcation diagram results of a complete, industrial-strength model, and also through comparison with experimental data, showing good agreement. The use of a simplified model produces here a more refined exploration of dynamical features of the system such as its bifurcational structure and basins of attraction. The engineering relevance of these results is also evaluated through the use of basins of attraction.

* Corresponding author.
E-mail address: jsouza@usp.br (J.R. de Souza Jr.).

0096-3003/$ - see front matter
doi:10.1016/j.amc.2004.12.005

Keywords: Nonlinear dynamics; Offshore platforms; Bifurcations; Basins of attraction

1. Introduction

During the past few decades large converted tankers, also called Floating Production Storage and Offloading units (FPSOs), have been deployed as platforms for the exploitation of offshore oil and gas fields. FPSOs have some advantages over other floating platforms. First of all, they often have lower initial costs; a semisubmersible oil platform is more expensive than a converted tanker. Secondly, the storage capacity of a converted tanker is much larger. Other reasons can be also pointed out, such as mobility. However, one significant disadvantage of such system relates to its dynamic behavior. The dynamic response of an FPSO tanker is that of an ordinary ship, therefore its motions due to external forces (such as waves, current and wind) can be considerably larger than those of a semisubmersible platform, particularly when environmental forces act upon the lateral of the vessel. Thus the FPSO has to be kept in place by a mooring system that connects it to the seabed. Two designs have been favored in recent times. The DIfferentiated Compliant Anchoring System (DICAS) is a spread mooring system which by careful choice of pretensions of mooring lines allows the vessel some freedom to rotate and self-align (partially) with the direction of resultant forces. Because of its limited ability to self-align, the FPSO's design alignment has to be judiciously chosen according to the predominant direction of incoming current and wind. The other mooring system often used is the Turret type, in which the FPSO has to be equipped with a revolving structure (the turret) that receives both the mooring lines and the risers (ducts that carry the products from the reservoir to the vessel). This is a more expensive and sometimes less robust design that has the advantage of allowing the FPSO total freedom of self-alignment with the weather.

Also significant is the fact that two-ship tandem configurations are employed during the offloading process, when a shuttle tanker is connected to the FPSO through an elastic cable (hawser) in order to take the cargo to onshore processing plants. During this process, more complex, dynamic scenarios are observed [1]. Depending on the external forces, the ships can display undesirable equilibrium points and/or motions that bring the vessels into dangerous proximity or unacceptable relative positioning [2]. This is regarded by operation crews as unsafe situations, and their prevention should ideally be made at the time of the system design. Good knowledge of the rich dynamic behavior exhibited by this system is therefore an essential step in the design process. Such knowledge starts with suitable mathematical models of the whole system, which take into account the hydrodynamic, aerodynamic, and elastic effects. However, a comprehensive investigation of such models is difficult to carry out due to the complexity of the