Quantifying intact ship capsizing risk

Synopsis

Intact ship stability is a vital issue in the maritime sector and an important part of the design specification when building ships. Underlying the stability criteria is the idea that a ship in upright position is only locally stable, and a large enough excitation by waves and steering response might topple the vessel over, leading to a capsize. In order to quantify the capsize risk, the ship's motion must be modelled by a dynamical system, depending on the hull form and the sea conditions. Traditional models are extemely simplified. This project aims to explore more complex models that incorporate stochasticity, to more accurately quantify the capsize risk.

Supervisors

Tobias Grafke (T.Grafke@warwick.ac.uk)
Robert MacKay (R.S.MacKay@warwick.ac.uk)

Background

Intact ship stability is one of the primary design criteria in the maritime sector. Traditional notions of ship stability and the rolling motion have resulted in an international safety standard (IS2008), but its mathematical modelling relies on drastic simplifications in the form of linearisation and small amplitude approximations. In particular, the susceptibility of the vessel to capsize due to parametric resonances, directional instabilities, etc, cannot be captured by such approaches.

Currently, a revision of the international intact stability criteria by the IMO is under way, and more sophisticated mathematical models and tools are desperately needed.

MSc Project aims and objectives

The main goal of the MSc project would be to investigate existing dynamical systems in the literature that model intact ship dynamics under the influence of periodic forcing by waves with random perturbations. Starting with simple 1-dimensional models for the roll, over 2-dimensional models for roll and pitch, and possibly considering more complicated models, safety criteria for capsize events could then be constructed using the theory of uniform hyperbolicity [1] to determine rigorous 'safety criteria' for aperiodically forced systems, i.e. conditions on forcing functions for which the response is guaranteed to remain within a specified 'safe' region. Alternatively, the capsizing event can be interpreted as rare event of a stochastic dynamical system leaving a metastable basin of attraction, the probability of which can be estimated via large deviation theory [2], yielding the most likely capsize trajectory.

The work will be accompanied by simple numerical simulations of the dynamical systems to verify the obtained results.

Intact Ship Capsize

A capsized cruise liner [New York Times]

PhD Project

Possible continuations of the miniproject involve considering more complicated models for ship motion, and working with naval engineers to establish a translation from the sea state into moments and forces. Using these improvements, more sophisticated safety criteria can be formulated, either in terms of dynamical systems and control theory or mean first passage times and large deviations.

Student Requirement

The objectives require basic knowledge in stochastic processes or dynamical systems. Further, prospective students should bring some prior experience in matlab, python, julia, or comparable.

References

[1] Z. Bishnani and R. S. MacKay, Dynamical Systems **18**, 107 (2003).

[2] T. Grafke and E. Vanden-Eijnden, Chaos: An Interdisciplinary Journal of Nonlinear Science **29**, 063118 (2019).