Graduate Student Research Seminar

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Parametric roll oscillations of a hydrodynamic Chaplygin sleigh

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Abstract

Biomimetic underwater robots use lateral periodic oscillatory motion to propel forward, which is seen in most fishes known as body caudal n (BCF) propulsion. The lateral oscillatory motion makes slender-bodied fish-like robots roll unstable. Unlike the case of human-engineered aquatic robots, many species of fish can stabilize their roll motion to perturbations arising from the periodic motions of propulsors. To first understand the origin of the roll instability, the objective of this paper is to analyze the parameters affecting the roll-angle stability of an autonomous fish-like underwater swimmer. Eschewing complex mod-els of fluid-structure interaction, we instead consider the roll motion of a nonholonomic system inspired by the Chaplygin sleigh, whose center of mass is above the ground. In past work, the dynamics of a fish-like periodic swimmer have been shown to be similar to that of a Chaplygin sleigh. The Chaplygin sleigh is propelled by periodic torque in the yaw direction. The roll dynamics of the Chaplygin sleigh are linearized and around a nominal limit cycle solution of the pla-nar hydrodynamic Chaplygin sleigh in the reduced velocity space. It is shown that the roll dynamics are then described as a nonhomogeneous Mathieu equation where the periodic yaw motion provides the parametric excitation. We study the added mass effects on the sleigh's linear dynamics and use the Floquet theory to investigate the roll stability due to parametric excitation. We show that fast motions of the model for swimming are frequently associated with roll instability. The paper thus sheds light on the fundamental mechanics that present trade-offs between speed, efficiency, and stability of motion of fish-like robots.

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