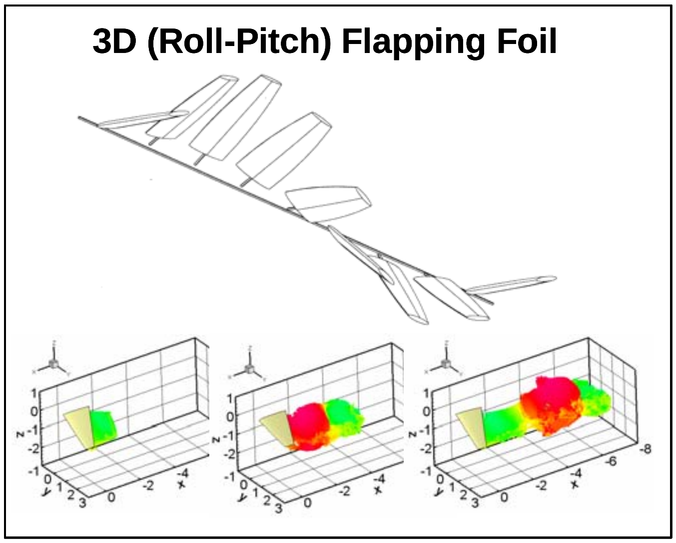
CEROS Project Description

Project: ***Demonstration of a 3-D Flapping Foil Motion Control System*** [1]

Contractor: **Science Applications International Corporation (SAIC), Annapolis MD, in collaboration with the Massachusetts Institute of Technology (MIT)**

Summary: This project endeavored to create a technology to improve ship motion control and maneuvering mechanisms, enabling stable operation of vessels in high seas at low and high speeds. It was demonstrated in simulation that a 3-D flapping foil can achieve roll reductions greater than 30%. Compared to a 2-D flapping foil, the 3-D flapping foil has much more complicated hydrodynamics characteristics, but has the advantage of being very effective at all ship speeds and being a stand-alone system that can easily replace existing motion control systems.

Description: This work is a study of a technology (equally effective across all ship operating speeds and environmental conditions) that could substantially improve ship motion control and maneuvering mechanisms. There is a large commercial and military demand for stable ship platforms that can operate safely in high sea states and at slow and fast speeds. Stable low speed platforms are required for landing helicopters, launching and retrieving of small boats or submersibles, and transferring personnel and cargo. Stable high-speed vehicles can be used to ferry passengers over significant distances with reduced motions compared to conventional ship types.



High-speed ships, SWATH vessels, and other advanced vessels currently use flaps, fins, and other forms of dynamic lift producing stabilizers to improve seakeeping and stability. Recent research projects at MIT and SAIC have demonstrated that a mechanized 2-D flapping foil or 3-D flap simulating the motion of a penguin wing could product large unsteady lifting forces in a very short period of time that cannot be obtained by conventional motion stabilizers. In particular, flapping wings are capable of producing large lifting forces in low ship forward speed cases. In this effort, 3-D flapping foil technology was employed to provide motion control on an advanced hull form.

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1 CEROS FY03 contract 50583 entitles *Development and Demonstration of a 3-D Flapping Foil Motion Control System for Advanced Marine Vehicles.*

The current project is a follow-on effort to an earlier CEROS project entitled *Flapping Foil Technology for Motion Stabilization of Novel High-Speed Vehicles*[2] . In that study, a series of 2-D flapping foil experiments were conducted, numerical simulations using the advanced computational fluid dynamics (CFD) tool FLEX3D were performed, and the 2-D flapping foil characteristics were mapped into numerical models. These models were integrated into the Large Amplitude Motion Program (LAMP), a physics based multi-level 3-D time domain simulation system for ship motion, wave loads, and structural response. At the conclusion of the FY01 study, a 3-D flapping foil motion control system was recommended. The 3-D flapping foil has much more complicated hydrodynamics characteristics, but has the advantage of being very effective at all ship speeds and being a stand-alone system that can be used to easily replace existing motion control system. In addition, it only requires the flaps, not the whole flapping foil motion control system, to move.

In this effort, a 3-D flapping foil motion control system was designed and numerically demonstrated for the 45-ft Small Water-craft Demonstrator (SDV-45) shown in Figure 2.

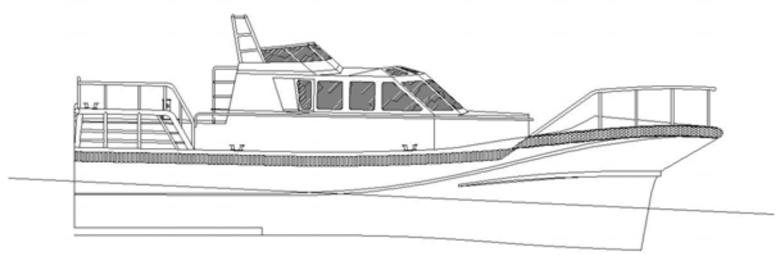

Figure 2. SDV-45 Profile

The performance of several 3-D flapping foils was determined based on numerical simulations using FLEX3D. The performance study included 3-D foil shape and type of motions especially the type of impulsive motions that can develop large transient forces for control. The performance results were used to build surrogate models for 3-D flapping foil performance. These models were integrated into the LAMP nonlinear time-domain ship dynamic simulation system, which was used to evaluate the ship motion and the performance of the 3-D flapping foil motion control system for SDV-45 operating in low-speed conditions. LAMP solves the three-dimensional time-domain nonlinear motion and load problems using a potential-flow boundary-element method, providing an accurate ship motion prediction and a time history of pressure load over the hull surface.

The final simulation system with imbedded flapping foil model was used to optimize the performance of the flapping foil system and the control algorithm. Three control algorithms – PID (Proportional, Integral, and Derivative), neural network, and adaptive moment control – were developed and used in LAMP to control the flapping motions.

The flapping foil was shown to have the following characteristic advantages over conventional motion control systems:

- Unsteady flow controlled by motions of a 2-D or 3-D foil can generate large propulsive thrust
- The addition of a pitch (twist) bias to nominal thrust trajectory creates mean lift coefficients as large as 4, while still producing positive thrust
- Still-water impulsive tests show that the peak forces are arbitrarily large; the maximum lift force coefficient during the move is 8 for a smooth trajectory
- Large forces can be generated by combination of many (high-frequency) flapping strokes

[2] CEROS FY01 contract 48211 with Pacific Marine & Supply Company Ltd.

Modeling results were obtained for sea state 3 (Figures 3, 4, and 5).

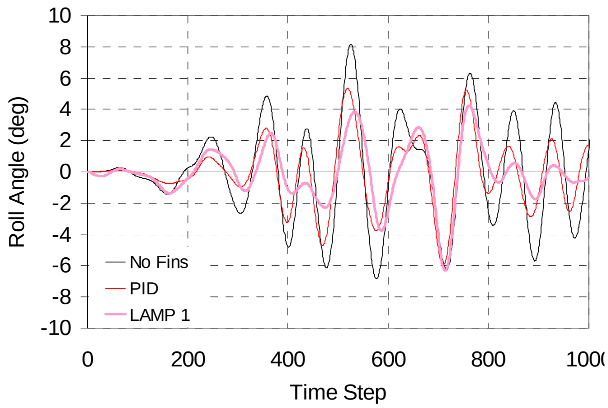

Figure 3. Rolling angle deflections. LAMP model #1 with (1) NN control: 48.02% Roll Reduction; (2) PID control: 39.2% Roll Reduction. Ship speed = 5 knots, Sea State 3

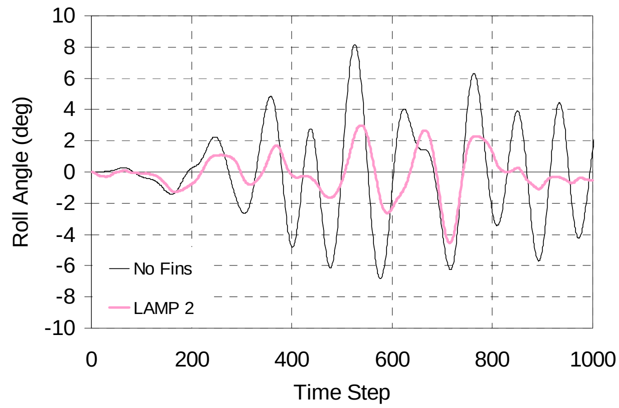

Figure 4. Rolling angle deflections. LAMP Model #2 with NN control. Roll Reduction: 62.4%. Ship speed = 5 knots, Sea State 3

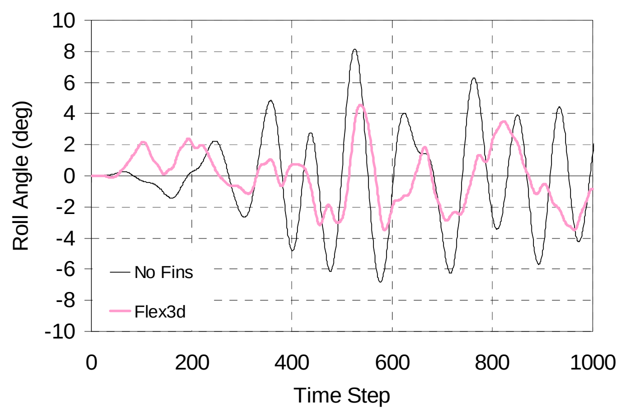

Figure 5. Rolling angle deflections. FLEX3D model with adaptive-moment control. Roll Reduction: 39.2%. Ship speed = 5 knots, Sea State 3

Four hydrodynamic models examined the effects of flapping foils on minimizing roll motion of the SVD-45 ship. The models have different levels of complexity from the simplest LAMP model #1 to the most complex VoLaR model. The FLEX3D model has also a large degree of sophistication, though its implementation in LAMP is based upon predetermined tables. All the hydrodynamic models used within the LAMP framework were capable of computing the ship motions under prescribed sea conditions.

From the simulation results, it appears that LAMP hydrodynamic models #1 and #2 give more roll-motion reductions. This is probably due to the fact that flow-separation effects were not considered in these models. The FLEX3D and VoLaR models yielded similar roll reductions, even when the controlling strategies were different. In all cases, the roll reductions obtained were greater than 30%.

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