DESIGN AND TESTING OF A VARIABLE GEOMETRY DUCTED PROPULSOR USING SHAPE MEMORY ALLOY ACTUATION

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SUMMARY

The concept of a steerable ducted propulsor is an attractive prospect for advancing a wide range of capabilities for naval submersibles such as submarines and Unmanned Undersea Vehicles (UUVs), and the extension of rapidly maturing smart materials technology offers a way to achieve this goal. In particular, the development of Shape Memory Alloy (SMA) actuation devices for underwater use has opened the way for a deformable 'Smart Duct'. This paper describes the Smart Duct concept, a ducted propeller with a deformable shroud that redirects the propeller wash to yield direct steering force via deformation provided by electrically-actuated nickel-titanium SMA wire actuators. The potential advantages of this steering control technology for naval applications include: enhanced low speed maneuvering for submarines; reduction or elimination of conventional steering surfaces and of associated actuator noise; and elimination of hydraulic actuation hardware in favor of all-electric components. The research described here included computational studies of candidate Smart Duct designs, a description of relevant SMA actuator technology, and a summary of model construction techniques for in-water testing. In addition, water tunnel testing of a 15" diameter demonstrator was conducted and results on measured forces and moments were compared with relevant computational modeling.

NOMENCLATURE

D = propeller diameter, m
J = advance ratio, V/nD
R = propeller radius, m
n = propeller rotation rate, 1/s
V = onset flow speed, m/s
δ = duct trailing edge deflection angle, deg.
ρ = density, kg/m^3
SMA = Shape Memory Alloy

1. INTRODUCTION

Current systems for turning and maneuvering control for naval vessels have a range of limitations. For submarines operating in a littoral environment, enhanced turning capability at low forward speed is highly desirable; improved maneuvering and performance would also benefit the coming generation of Unmanned Underwater Vehicles (UUVs). For surface combatants, the ability to maneuver while minimizing or eliminating cavitation-induced noise due to propeller wash impingement on a rudder is a high priority. In all these applications, development of technologies that minimize the use of high-maintenance actuation (e.g., hydraulics) in favor of electrical systems are an important long-term priority for cost savings and for enabling new designs that save space and weight and minimize hull penetrations.

Ducted propulsors have been assuming a growing role in naval combatants, and the concept of a steerable ducted propulsor – one whose outflow can be redirected to enhance low speed maneuvering and augment the performance of (or replace) conventional rudders or sternplanes – is an attractive prospect for addressing these needs. However, mechanical implementation of such a concept through hydraulic or electro-mechanical actuation would in many circumstances be prohibitively difficult. The extension of rapidly maturing smart materials technology, however, offers a realistic path to achieving this goal. In particular, the development of practical Shape Memory Alloy (SMA) actuation devices for underwater use has opened the way for a deformable 'Smart Duct'.

Figure 1 depicts the overall concept of this system: a ducted propeller with a deformable shroud that redirects the propeller wash to provide direct steering force. At the same time, the induced flow over the duct generates substantial side forces that make this system more effective in providing steering forces than vectored open propellers at an equivalent slipstream deflection. As is discussed below, the deformation is provided by an electrically-actuated steel structure – embedded in flexible, hydrodynamically smooth sheathing - whose prime movers are a set of high strength nickel-titanium SMA actuator cables.

This paper is a summary of recent work whose central objective was to design and build a Smart Duct technology demonstrator suitable for in-water testing at approximately 1/12th scale. Given the prior work described below, this was judged to be the most appropriate focus for technology

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