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HYDRODYNAMIC TESTING OF UNDERWATER VEHICLES AT THE AUSTRALIAN MARITIME ENGINEERING CO-OPERATIVE RESEARCH CENTRE

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Abstract- The Australian Maritime Engineering Co-operative Research Centre (AMECRC), in collaboration with the Defence Science and Technology Organisation (DSTO) and Curtin University, has been involved in the determination of the hydrodynamic characteristics of uninhabited underwater vehicles (UUVs) used by the Royal Australian Navy (RAN) and the offshore oil and gas industry. These characteristics are essential for the design of low level motion controllers and for the development of computer simulations. DSTO has designed and built a Horizontal Planar Motion Mechanism (HPMM), the first facility of its type in Australia, specifically for the determination of the manoeuvring characteristics of UUVs. The capability of the HPMM facility, and of the additional facilities located at the Australian Maritime College (AMC), are presented. The preliminary results of a recent project is also presented. The aim of the project was to determine the effect on the manoeuvring characteristics of a generic flat-fish UUV of presence of lateral thruster ducts.

INTRODUCTION

The design of motion controllers, the training of vehicle operators and even aspects of mission planning and the development of tactics all rely upon realistic simulation of the underwater vehicle. The development, in turn, relies upon the fidelity of the hydrodynamic characteristics of the vehicle. DSTO, in conjunction with AMECRC, have designed and built at the AMC in Launceston, Australia, the HPMM for the measurement of the hydrodynamic and manoeuvring characteristics of scale model UUVs.

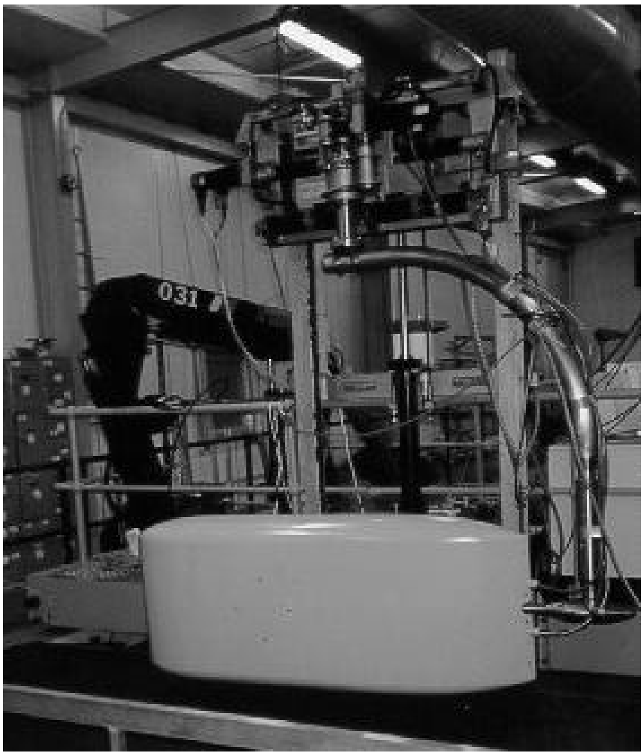
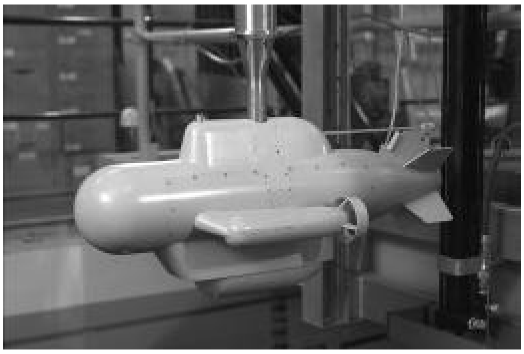
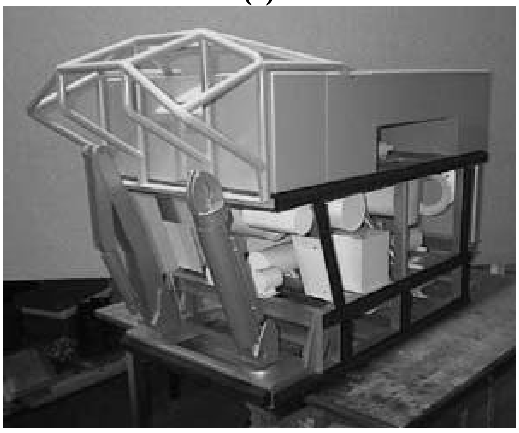


Figure 1 The hydrodynamic model of the general flatfish UUV without the tunnel thruster attached to the Horizontal Planar Motion Mechanism.

The HPMM, shown in Figure 1, has so far been utilised to determine the manoeuvring characteristics of several UUVs for the RAN and for the offshore oil and gas industry, including the PAP 104 [1] (see Figure 2(a)), and Double Eagle [2] mine disposal vehicles, and the Perry-Tritech ‘Triton’ work class vehicle (see Figure 2(b)) [3]. Experiments on fundamental ellipsoid and sphere shapes have also been performed, and even the manoeuvring characteristics of a bulk cargo carrier [4] have been determined.



(a)



(b)

Figure 2 Hydrodynamic model of the (a) the Pap 104 mine disposal vehicle and (b) Triton work class vehicle.

THE HORIZONTAL PLANNAR MOTION MECHANISM

The HPMM was designed and built by the DSTO, and completed as part of its contribution to the AMECRC. The operation of the HPMM and a comprehensive description of the motions are provided by Anderson [5].

The HPMM is positioned on a mounting frame on a carriage over the Circulating Water Channel (CWC), which may be driven to any position over the test section (see Figure 3). Scale models are attached to the HPMM using a strut mount that runs vertically from the rotation post to the top of the model, or more often using the sting arm attachment that enters through the rear of the model. Two servo-motors are used to provide the HPMM motions: one is dedicated to providing translation and the other rotation. The motors are driven under closed loop control by an IBM PC. However, since the motors are independently controlled, the HPMM is also capable of providing non-sinusoidal motions, within the limitations of the mechanism [6].

The maximum static rotation in the horizontal plane is ±90°. In the dynamic mode, the maximum peak to peak horizontal oscillation is 0.30m and the maximum peak to peak rotational oscillation is 30°. The oscillatory frequency ranges from 0.01 Hz to 0.20 Hz. The maximum translational rate is therefore 0.19 m/s.

Loads on the model are measured concurrently with the angular and positional displacement of the model in the flow. The force and moment data are used to determine the model's manoeuvring behaviour, which is characterised by 'hydrodynamic coefficients' or 'derivatives'. These can then be scaled to the full dimensional size of the corresponding vehicle and used in simulation codes for determining the vehicle's stability and manoeuvring performance, and in designing automatic control systems.

The HPMM has two modes of operation: namely the 'static' and 'dynamic' modes. The static mode allows the models to be held stationary relative to the moving flow at various angles of incidence. In the dynamic mode, the HPMM moves in translation and rotation relative to the water velocity. Two commonly used dynamic motions are pure sway and pure yaw. Pure sway is imparted to the model by oscillating it across the width of the water channel while the model's heading is set to zero, ie. directly into the flow. The motion imparted to the model is sinusoidal, and the lateral displacement of the model is given by the expression

$$y = y_o \sin \omega_t t \qquad (1)$$

where y_0 is the amplitude of the sinusoidal motion, w_t is the frequency of the translation oscillation, and *t* is the time.

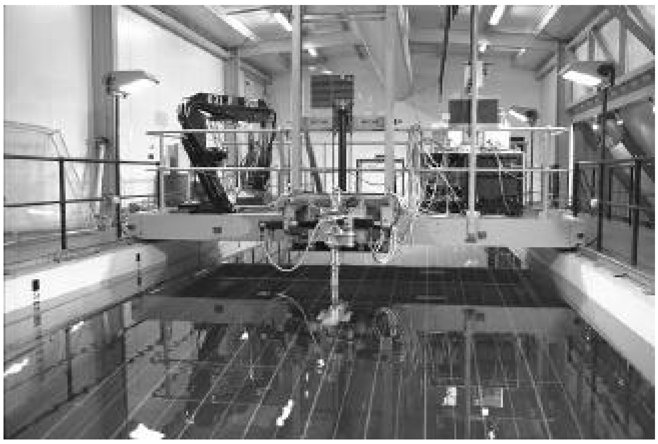


Figure 3 The HPMM lowered in the Circulating Water Channel.

Pure yaw motion involves oscillating the model cyclically in rotation and translation. However, for pure yaw to exist, the

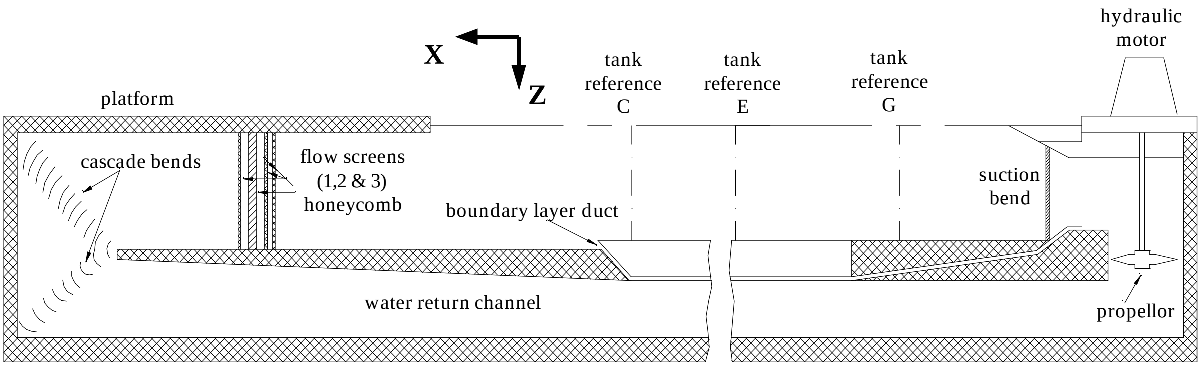


Figure 4 Schematic of the Circulating Water Channel [5]

body x-axis must be coincident with the tangent of the model's path, ie.

$$\tan\psi = \frac{\dot{y}}{U_f} \qquad (2)$$

where U_f is the tank water flow speed.

The angular displacement is driven in sinusoidal motion by the HPMM, given by

$$\psi = \psi_o \sin \omega_r t \qquad (3)$$

where y_o is the maximum amplitude of the angular oscillation, and w_r is the frequency of the angular oscillation.

Substituting for y in Equation (2) and then integrating gives the Y-axis (across the width of the channel) displacement of the body as

$$y = U_f \int \tan(\psi_o \sin \omega_r t) \qquad (4)$$

THE HYDRODYNAMIC FACILITIES AT THE AMC

There are three world class hydrodynamic facilities located at the Australian Maritime College campus in Launceston, Australia: the Circulating Water Channel, the Tow Tank Facility and the Cavitation Tunnel.

The CWC is shown schematically in Figure 4, it has a working section 17.2 m long, 5.0 m wide and 2.5 m deep, and forms a continuous circuit for 700,000 litres of water. Flow speeds up to a maximum of 1.5 m/s are generated by four 56.5 kW axial flow pumps located at the downstream end of the channel. Water is pumped into a return channel beneath the test section, then through two 90° cascade bends, and a honeycomb of turbulence reduction screens, before re-entering the test section of the channel. A conveyor belt is located at the base of the channel to inhibit the formation of a viscous boundary layer. The flow quality, uniformity and turbulence levels within the channel have been studied and progressively improved by Anderson [5], and more recently by Maynard *et al.* [7]. The principal advantage of using a CWC for hydrodynamic testing is the unlimited run-time, which allows the water to flow continuously past the model. Hence steady state flow may be maintained indefinitely and the duration of tests can be as long as necessary. This allows the HPMM testing to be extended to lower frequencies if necessary.

The Tow Tank facility is used for higher speed straight line drag experiments. The model is dragged at speeds of up to 4 m/s through a 60 m long stationary body of water. The results obtained for the hydrodynamic forces and moments due to forward motion are highly repeatable, with less variance than can be provided by the HPMM. The Cavitation Tunnel is used to study the flow around high-speed objects including torpedos, hydrofoils, propellers and water jet intakes. It can produces a low turbulence flow within its test section ($0.6m^2$ x 2.6m) at velocities of up to 12 m/s. The facility may run at static pressures between 10 and 400 kPa.

DETERMINATION OF THE HYDRODYNAMIC DERIVATIVES FOR A GENERIC FLATFISH UUV

Flatfish type UUVs are becoming common for mine detection and classification roles. The RAN for example operates the Bofors Double Eagle and DSTO has designed and built a 6 thruster UUV, Wayamba, to investigate underwater technologies. In order to simulate the performance of these flatfish UUV, scale models have been evaluated on the HPMM. These models however are smooth shell representations of the actual vehicle, neglecting protrusions due to instrumentation, such sonar, umbilical attachment points, and in particular thruster ports.

In order to quantify the effect that thruster ports have on the ideal model's manoeuvring characteristics, a generic flatfish shape was evaluated with and without the presence of a thruster port. The smooth skin model is shown on the HPMM in Figure 1 while Figure 5 shows the model in the CWC with the inclusion of the thruster duct. The body reference X-axis is extends from the centre of the thruster towards the front of the vehicle, the Y-axis is to starboard and the Z-axis is directly down.

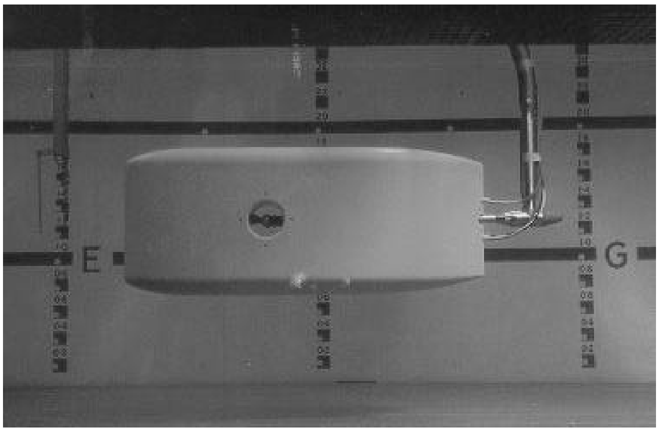


Figure 5 The generic flatfish UUV in the CWC with a centrally located tunnel thruster.

The models are 1.95m long, 0.8m high and 0.4m wide. The tunnel thruster has a diameter of 0.2m and is located 0.775m from the nose of the model. The shaft of the thruster is positioned along the centre-line of the model with the kaplan propeller attached via a right angle drive. The propeller therefore sits not on the centre-line but closer to the port side entrance to the duct. The two models were yawed between the angles of ±20° for flow speeds of 0.3 m/s, 0.6 m/s and 1.0 m/s. The model was mounted on two AMTI, one either side of the thruster duct, which in turn were supported on a strong back. The forward load cell is attached to the model via a hinge joint with the rear is attached to the model using a pivot/slider joint that is not constrained in the X direction. The drag, F_x, was measure by the forward load cell alone, the side force, F_y and the yaw moment, M_z, defined from the centre of the thruster duct, were measured using both the load cells.

Figures 6 to 8 show the non-dimensionalised F'_x, F'_y and M'_z respectively, for the model with and without the tunnel thruster for each of the flow speeds. The forces were non-dimensionalised using:

$$\tfrac{1}{2}\rho U^2 L^2 \tag{5}$$

while the yaw moment was non-dimensionalised using;

$$\tfrac{1}{2}\rho U^2 L^3 \tag{6}$$

where ρ is the density of water, 1000 kg/m^3, U is the flow speed in m/s, and L is the characteristic length in m and was taken as the length of the model, 1.95m.

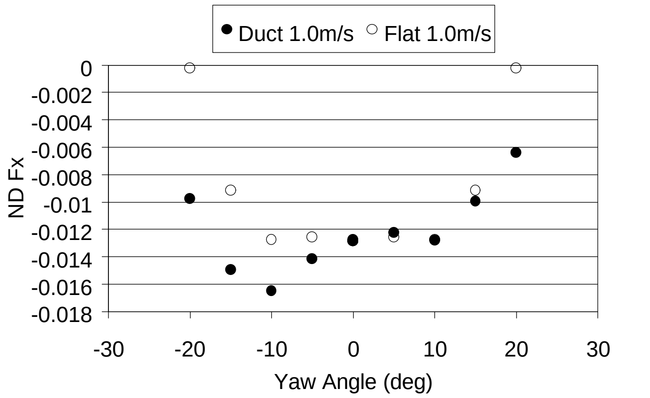


Figure 6 Comparison of the non-dimensional drag (F_x) force at a flow speed of 1 m/s, for the generic UUV with and without the presence of a thruster duct.

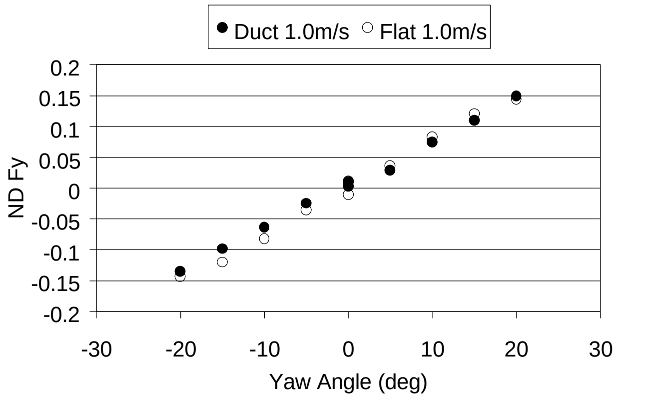


Figure 7 Comparison of the non-dimensional transverse (F_y) force at a flow speed of 1 m/s, for the generic UUV with and without the presence of a thruster duct.

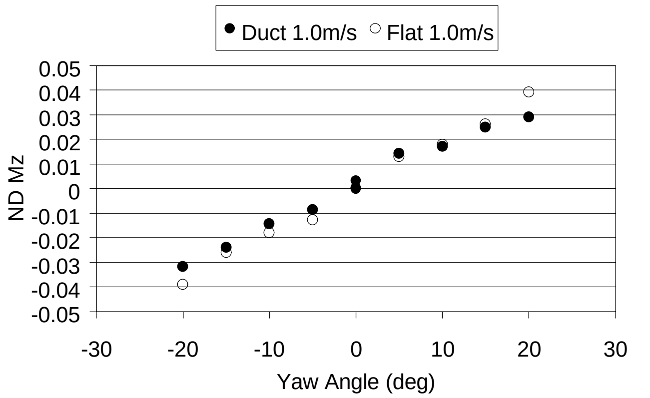


Figure 8 Comparison of the non-dimensional yaw (M_z) moment at a flow speed of 1 m/s, for the generic UUV with and without the presence of a thruster duct.

The non-dimensional hydrodynamic derivatives were determined by fitting the non-dimensional forces and moments as functions of the non-dimensional velocities. The forces and moment were modelled by

$$F'_x = X'_{uu}\, u'^2 + X'_{uv}\, u'v' + X'_{vv}\, v'^2 + X'_{v4}\, v'^4 \qquad (7)$$

$$F'_y = Y'_{uu}\, u'^2 + Y'_{uv}\, v' + Y'_{v|v|}\, v'|\, v'| \qquad (8)$$

$$M'_z = N'_{uu}\, u'^2 + N'_{uv}\, u'v' + N'_{v|v|}\, v'|\, v'| \qquad (9)$$

Table 1 The hydrodynamic derivatives of the generic flatfish UUV with covers over the thruster ports. The derivatives have been evaluated separately for each of the flow speeds.

	0.3m/s	0.6m/s	1.0m/s
X'_{uu}	-0.009	-0.010	-0.013
X'_{vv}	0.091	0.096	-0.037
X'_{v4}	0.193	0.009	1.123
Y'_{uv}	-0.312	-0.377	-0.462
N'_{uv}	-0.113	-0.110	-0.109

Table 2 The hydrodynamic derivatives of the generic flatfish UUV with the thruster ports open to the flow. The derivatives have been evaluated separately for each of the flow speeds.

	0.3m/s	0.6m/s	1.0m/s
X'_{uu}	-0.008	-0.008	-0.013
X'_{uv}	-0.019	-0.010	0.008
X'_{vv}	0.021	-0.040	-0.071
X'_{v4}	0.411	0.735	0.864
Y'_{uu}	0.002	0.001	0.004
Y'_{uv}	-0.287	-0.354	-0.424
$Y'_{v\|v\|}$	-0.010	-0.090	-0.026
N'_{uu}	-0.002	0.001	0.000
N'_{uv}	-0.120	-0.098	-0.095
$N'_{v\|v\|}$	-0.006	0.036	0.013

Table 1 shows the hydrodynamic derivative for the smooth skin model, without any interaction from the thruster ducts. Due to the symmetry of the model, the derivatives X'_{uv}, Y'_{uu} and N'_{uu} equalled zero. In addition the non-linear derivatives, $Y'_{v|v|}$ and $N'_{v|v|}$ were not strongly excited and therefore also equalled zero. Table 2 shows the derivative of the generic UUV with the thruster ducts open to the flow. The effect on the manoeuvring characteristics due to the presence of the thruster duct is only marginal. Some additional asymmetric and non-linear derivatives have become excited. The appearance of the asymmetric derivatives in the open duct condition may be due to the asymmetric positioning of the propeller closer to the port entrance to the duct.

ACKNOWLEDGEMENTS

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