DEVELOPMENT OF A HORIZONTAL PLANAR MOTION MECHANISM FOR DETERMINING HYDRODYNAMIC CHARACTERISTICS OF UNDERWATER VEHICLES

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ABSTRACT

A Horizontal Planar Motion Mechanism (HPMM) has been developed by the Defence Science and Technology Organisation (DSTO) in collaboration with the Australian Maritime Engineering Cooperative Research Centre (AMECRC) for measuring the hydrodynamic characteristics of underwater vehicles. The HPMM has been installed at the Australian Maritime College's (AMC) circulating water channel (CWC) located at Beauty Point, Tasmania. The HPMM is currently configured to test submerged models with a rigid single strut mounting arrangement. Further development will involve the use of the HPMM for testing surface vessel models in the AMC's towing tank facility.

The HPMM installation has undergone an extensive commissioning and calibration phase to determine mechanism related effects and the accuracy of the mechanism. The CWC flow quality has been investigated and some improvements to the flow uniformity have been implemented.

A set of HPMM experiments has been carried out on a sphere and a 1/3rd scale model of a typical remotely operated vehicle. Initial results indicate that the model/strut interaction has introduced some variation in forces acting on the models. This problem is discussed along with possible solutions.

INTRODUCTION

The HPMM is a mechanical device that has been traditionally designed to impart controlled cyclic rotational and translational motions (generally sinusoidal) to a model in the presence of a water flow. The water flow is generated either by towing the model along a water tank or by holding the model stationary and circulating the water past it in a facility such as a CWC.

The resulting hydrodynamic loads from the HPMM testing are measured and processed to determine the hydrodynamic 'coefficients' or 'derivatives' which characterise the vehicle's manoeuvring.

The installation of the HPMM facility in Australia has established a capability that has previously existed in only a few overseas countries. Since the late 1950's, HPMMs have been used to characterise the hydrodynamics of both surface and submerged vehicles. The capability to determine the parameters necessary for accurate simulation, design and performance evaluation of marine vessels will greatly benefit the Australian maritime industry.

THE DSTO HPMM

The HPMM, designed by DSTO, was completed as part of its contribution to the AMECRC. Figure 1 illustrates the HPMM and its strut mounting arrangement with a sphere model attached. The cut-out drawing of the sphere illustrates a six-axis load cell mounted in-line with the strut and a rigid bulkhead within the sphere. The load cell (Advanced Mechanical Technology Inc, Model MC3A-6-250) is capable of measuring three forces and three moments. It is important to note that the load cell is mounted inside the models. The only hydrodynamic load experienced by the load cell will be that acting on the test model.

The DSTO/AMECRC mechanism can be operated in two modes, static and dynamic. In the dynamic mode, the HPMM oscillates in the horizontal plane and can provide yaw and sway motions with models mounted in an upright position; the same motions applied to a model mounted on its side will produce pitch and heave relative to the model. The static mode allows the models to be held stationary relative to the moving flow, at various angles of incidence.

Two servo motors are used to provide the motions, with one dedicated to providing translation and the other rotation. The motors are driven under closed loop control

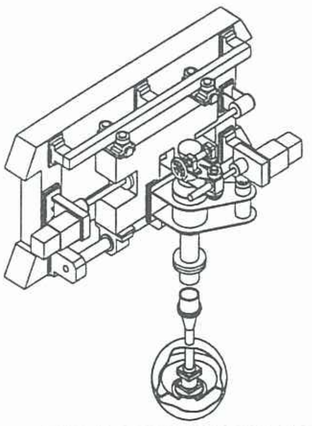

FIGURE 1. THE DSTO/AMECRC HORIZONTAL PLANAR MOTION MECHANISM

of an IBM PC. The maximum static rotation in the horizontal plane is +/- 45 degrees. In the dynamic mode, the maximum peak to peak horizontal oscillation is 0.30m and the maximum peak to peak rotational oscillation is 30 degrees. The oscillatory frequency ranges from 0.01 Hz to 0.2Hz. The maximum translational rate is therefore 0.19m/s.

Forces and moments are measured by a six-component strain gauge load cell. The actual motions performed by the model are also measured with translational and rotational transducers fitted to the mechanism.

Data is acquired on a separate PC-based data acquisition system. The force data is synchronised with the mechanism's position at a given time, as well as the flow velocity.

Until recently PMMs were based on a mechanical slider-crank, scotch yoke arrangement so that only sinusoidal motions were possible in the dynamic mode of operation. The DSTO/AMECRC HPMM produces these sinusoidal motions, but may also be programmed to generate any other motions within the limitations of the mechanism. This ability to program the mechanism with arbitrary motions has been used to compensate for non-linearities inherent in the design of the rotational actuators.

PMM DATA ANALYSIS

There are several methods of PMM data analysis described in the literature. Booth and Bishop (1973) and Renilson (1986), describe HPMM dynamic data analysis procedures which take advantage of the sinusoidal nature of the forces and moments measured from oscillatory testing. This testing introduces a frequency effect that is accounted for in the results. The dynamic data analysis methods extrapolate the data to find the hydrodynamic coefficients at zero frequency (ie. as though no oscillatory motion were used to determine the coefficients.) For this reason the coefficients are sometimes known as "slow motion derivatives".

Other methods of analysis (Jensen(1986)) ignore the frequency or "time history" effects by introducing a "quasi-static" assumption, whereby each dynamic measurement made at each point in time becomes a static measurement. Coefficients are found from an overdetermined set of equations using least squares regression in this case.

The method chosen to determine the hydrodynamic coefficients from the HPMM testing data must be consistent with the mathematical model used for manoeuvring predictions, as the coefficients themselves may differ depending on the method of analysis.

CHOICE OF WATER TANK FACILITY

Captive model tests such as those involving the use of a HPMM or a VPMM (Vertical Planar Motion Mechanism) have generally been performed in towing tanks in the past.

The AMC's towing tank and CWC were the two alternative facilities considered for the use of the DSTO/AMECRC PMM. The CWC facility was chosen from considerations of blockage, tank wall, free surface effects and model Reynolds number.

Blockage ratio is defined as the ratio of the model cross-sectional area to that of the tank. Resistance tests for submerged models have showed that a blockage ratio of 0.02 or less is acceptable (Sayer and Baker (1988)).

Tow Tank

The AMC tow tank has dimensions of 70m length, 2.5m width, and 1.5m depth with a cross-sectional area of 3.75m^2. The blockage ratio for models of approximately 1.0m length and 0.5m width, is 0.13. This figure is much greater than the accepted value of 0.02.

Tow tank testing has several advantages. Principally, the uniform flow that can be sustained over the model for the duration of the run down the tank. Tow tank facilities can also provide a very low turbulence environment with appropriate settling times. The water speed past the model is easily measured by the speed of the towing carriage. Given this, the force measurements can be reduced to coefficients quite accurately. This is in contrast to CWCs, where spatial nonuniformities are common and introduce error into the hydrodynamic coefficients.

However, the length of the AMC tow tank limits the HPMM frequencies that can be tested. A frequency of 0.01 Hz requires 100 seconds for 1 cycle to be completed. If model tests were performed at a velocity of 0.6m/s then 60m of tank would be required to conduct the test. This does not include the acceleration and deceleration length required. Either larger frequencies or lower speeds are required for a testing in the tow tank. Another feature of the tow tank is that it requires time for the water to settle after each run, which adds to the duration of the program.

Circulating Water Channel (CWC)

The AMC CWC has a working section which is 17.2m long, 5.0m wide and 2.5m deep, and forms a continuous circuit for 700,000 litres of water. Four hydraulic motors driving parallel 1.2m diameter axial pumps produce circulatory water flow at variable speeds up to a maximum of 1.4m/s in the working section.

The principal advantage in using a CWC for hydrodynamic testing is the unlimited run-time length, which is not available in a towing tank facility. Since the water flow passes the model continuously, and assuming no variation in the flow speed over time, the duration of tests can be as long as necessary. The resulting ability to extend the HPMM testing to low frequencies reduces the need for extrapolation of the data.

The blockage ratio for the CWC and the model dimensions given above is 0.04. This is more acceptable than the 0.13 for the tow tank. For these reasons the CWC was chosen for the HPMM testing of submerged models.

TABLE 1. CWC SPATIAL FLOW VARIATION

Screen Open Area Ratio %			Horizontal % RMS		Vertical % RMS	
1	2	3	TS	WS	TS	WS
-	68	-	3.0	3.5	10.1	4.7
-	68	64	2.4	1.8	6.1	3.1
58	64	69	2.9	2.1	3.0	2.4

CWC Flow Environment

Spatial nonuniformities and increased turbulence levels in the water flow pose the greatest problems for HPMM testing in a CWC. The conditions are exacerbated in the AMC CWC by the working section inlet comprising an expansion rather than a contraction. The flow profile in the AMC CWC was measured at a range of positions between 0.5m from each side wall and 0.1m from the surface and bottom, and found to have significant spatial variations in the time mean flow.

Options for improving the flow quality in wind tunnels are discussed in the literature (e.g. Bradshaw and Pankhurst (1964) and Mehta (1977)). Some of the methods include graded or shaped wire screens, and an optimally designed honeycomb. The optimal positioning of multiple screens relative to each other is also discussed. These methods are also relevant to water tunnels.

In an effort to improve the flow quality, an inspection of the CWC facility revealed several options for reducing the nonuniformities. One approach was to install further wire mesh flow conditioning screens. Table 1 shows the results of flow profile tests that were taken in the AMC CWC as the screens were installed. The values given in this table are the percentage RMS deviations from the time-mean velocity of the flow in the horizontal or vertical section. TS indicates the RMS values for the horizontal range between 0.5m from both tank walls, and the range between 0.1m from the surface and floor in the vertical. The values given under WS indicate a more tightly defined region, this being 1.8m from the walls in the horizontal and 0.6m from surface and floor in the vertical.

The original CWC configuration consisted of a honeycomb with a flow conditioning screen immediately downstream. There were three possible positions for screens to be implemented in the tank; the position just described is denoted as 2 in Table 1. A screen position available 190mm downstream denoted as 3, while the remaining position denoted as 1, is positioned 695mm upstream from the honeycomb. The original screen, placed in position 2, had an open area ratio of 68%. A screen with an open area ratio of 64% was installed in position 3. The results in Table 1 show a significant reduction in the spatial nonuniformity in the flow. The success of the new screen suggested that implementing a third screen in the remaining available position might further improve the flow quality. The next exercise involved several steps: the 64% screen was placed in position 2; the 68% screen was rewired with 58% open area ratio and placed in position 1; a new screen was built and wired to 69% open area ratio and placed in position 3. The new screen arrangement improved the flow variation significantly in the vertical profile; fluctuations in the horizontal profile appear marginally worse, but this may be an artefact of current problems in setting uniform pump speeds. Further work is needed to resolve this question and optimise the screen configuration.

The discharge from the pumps was another factor which could influence the quality of the flow. The discharges from the four pumps were measured and found to differ significantly. Further investigation revealed the lack of any closed loop feedback control on the pump motor speed.

A controller for the synchronisation of the hydraulic motors is now being sought. The controller under consideration will allow the CWC flow profile to be "tuned", with several options for the type of feedback given to the controllers. This should enable the horizontal spatial variation in the flow to be further reduced. The controller reference may also be used to provide a standard reference for velocity measurements made in the tank.

CWC Turbulence

Direct measurements of turbulence in the CWC have yet to be made. The effects of the turbulence on force measurements are being studied at present. A series of drag measurements involving a model sphere of diameter 0.4m were recently carried out in both the AMC towing tank and the CWC. The results from these tests are shown in Figure 2. They have two notable features. First, the lower critical Reynolds number for the sphere in the CWC compared to that obtained in the tow tank. Although some error may have arisen from the spatial velocity variation, turbulence in the CWC not present in the tow tank mainly accounts for the difference. Strut interference may also have influenced the tow tank's critical number, which differs from Newman's (1977) critical Reynolds number of $3x10^5$. The second feature to point out is the lower sphere drag coefficient in the CWC after transition. This is attributed to support interference locally altering the position of flow separation. Note that both the CWC and tow tank results show higher drag coefficients than those given in the literature after transition, although the results are consistent with the literature at subcritical Reynolds number.

CALIBRATION OF THE HPMM

There are several aspects to the calibration of the mechanism. The calibration of the instrumentation including the load cells and velocity measurement logs is required along with confirmation that the motions

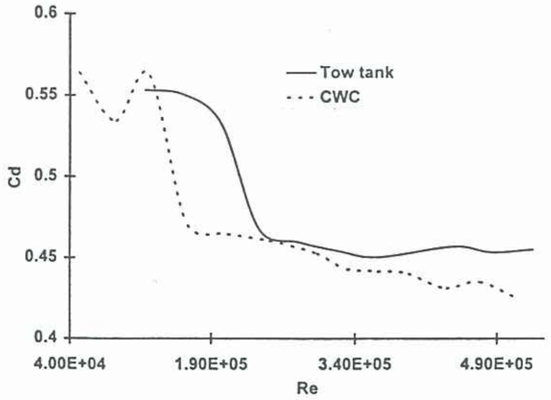

FIGURE 2. MEASURED DRAG COEFFICIENT FOR A SPHERE MODEL

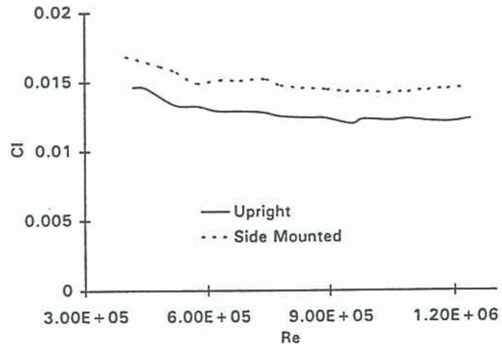

FIGURE 3. MEASURED LIFT COEFFICIENTS OF A MODEL ROV

performed by the mechanism comply with those required.

The mechanism has been calibrated and tested under load, and found to meet specification. Further analysis of data is required to complete the commissioning of the system as a whole ie. the production of reliable coefficients from HPMM testing.

MODEL/SUPPORT INTERACTIONS

Additional loads caused by the flow interactions between the mechanism strut and models were observed in initial tests. Figure 3. shows the variation with Reynolds number of the lift coefficient for a model vehicle mounted to the HPMM in two different positions, plotted against Reynolds number. The vertical axis gives the non-dimensional lift coefficient denoted by Cl, and the horizontal axis gives Reynolds number denoted by Re. The solid curve represents the model mounted in an upright position, while the broken curve represents the same model mounted on its side. The heave force relative to the model was measured in both cases. (Note the load cell was zeroed at the beginning of both test series.) As the experimental setup was unchanged, except for the model orientation relative to the strut, the difference in the curves was explained by the interference from the strut locally altering the location of flow separation.

An alternative mounting arrangement is currently being designed. This will be a "sting" type where the model is mounted from behind and the support lies in its wake. The use of the "sting" is expected to significantly reduce the support/model interference. The equations of motion for the HPMM with the new support will remain unchanged, even in the dynamic mode. It is intended that the load cell origin with respect to the mechanism will be unchanged in the new design.

CONCLUDING REMARKS

Further analysis of data is needed to fully determine the effects encountered from HPMM testing in a CWC. Measurements of the turbulence levels are still required and the effects of the flow screens have to be studied. The implementation of pump speed controllers for further flow improvement, and the construction of a "sting" mounting arrangement for test models should enable the HPMM facility to produce force data from which reliable hydrodynamic derivatives can be determined.

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