RN ENGINEERING COLLEGE, MANADON, POST-GRADUATE PROJECTS

The Royal Naval Engineering College provides two MSc courses, namely the MSc in Marine Engineering (AMEC) and the MSc in Maritime Defence Technology (AMDTC). One element of each of these courses is an individual research project undertaken by each officer, full time, over some 17 weeks during the final part of the course. Summaries of the projects undertaken by the officers of the 1989–90 MSc Course in Marine Engineering (AMEC 25) and the 1989–90 MSc Course in Maritime Defence Technology (AMDTC 89) are given below.

MSc COURSE IN MARINE ENGINEERING (AMEC 25) PROJECT SUMMARIES

An Electrical Propulsion Design Package
by Lieutenant T. Johns, MSc, RN

Future generations of warships are likely to be propelled electrically over their entire operating range. Although the advantages and disadvantages of electrical propulsion are well documented, the potential of each design option is often difficult to quantify.

A PC-based design package has been developed which will identify the size, weight and cost of varying types of electrical propulsion, along with specific areas of technical risk. In addition, the use of more novel designs such as direct water-cooling of conductors are considered and their effect is quantified. The performance of each option is evaluated with an emphasis on the harmonics generated in the converter which in turn affects both the supply and motor waveforms.

Condition Monitoring of Large Electrical Machines
by Lieutenant R. W. Jones, MSc, CEng, MIMarE, RN

Rotating electrical machinery has generally been considered reliable, requiring little attention except at infrequent intervals when the plant is shut down for inspection. In recent years however, electrical machines have been designed to tighter margins and, to maintain a high level of reliability, it is becoming increasingly important that the onset of faults is detected before the machine fails. To achieve this without withdrawing the machine from service requires non-intrusive assessment of machine behaviour and performance.

This project commenced with a survey of available condition monitoring techniques for electrical machines. This included an evaluation of the Entek Motormonitor system. Particular emphasis was given to condition monitoring techniques suitable for large, converter-driven, synchronous machines in a marine environment.

A test rig was then established on which various electrical faults could be imposed on an inverter-driven a.c. motor. Experimental work was carried out to assess two techniques for detecting faults on this rig. Results showed that two types of stator winding fault can be detected by frequency analysis of either stator or rotor current. The analysis was straightforward using conventional current sensors, and would be suitable for use on a synchronous marine propulsion motor. Certain other types of sensor were also considered suitable for use on this type of motor, and a practical assessment is suggested as the basis for further work.

Investigation of the Control Aspects of using the Rudder to assist Conventional Fin Stabilizers to improve Roll Reduction
by Lieutenant S. W. Braham, MSc, RN

The effectiveness of a Rudder Roll Stabilization system is primarily governed by rudder response. A measure of roll reduction can be achieved using existing rudder systems. The use of an existing rudder system to assist rather than replace fin stabilizers, appears to provide an inexpensive method for enhancing the roll reduction presently achieved. In addition, this approach provides the command with the flexibility to select the mode by which stabilization is achieved as dictated by operational requirements.

This report describes the development of warship and sea state disturbance models that generate roll motions reflecting those experienced at sea. An integrated rudder and fin stabilization control strategy is proposed and rudder roll controllers developed using a decoupled roll and yaw channel approach. Classical frequency domain sensitivity analysis techniques are used to refine controller designs. Simulation studies are described that quantify the performance characteristics of the proposed control strategy. The performance of a 'fast' rudder system is compared.

This study concludes that the proposed control strategy provides an inexpensive and effective method for substantially improving upon the roll reduction presently achieved whilst creating minimal yaw disturbance. The proposed strategy, using existing sensors and actuators, requires minimal additional hardware and expenditure to implement. The study has concentrated on the application of the strategy to a Type 22 frigate but the approach is suitable to all present and future warship designs fitted with active roll stabilizer fins.

A Fuzzy Rule Based Depth Autopilot for a Submarine in a High Speed Turn
by Lieutenant J. D. B. Barratt, MSc, RN

Keeping steering control of a submarine is a complicated problem. The cross-coupling of heave and roll forces during a tight turn, where the hydrodynamic characteristics are non-linear, makes the control problem more complex. At high speed and during a tight turn the submarine can experience depth excursions outside the compensating ability of the autopilot.

This project investigates the problem of depth keeping when conducting a high speed turn using a multi-input, single-output Fuzzy Logic controller, with an element of feedforward control. The controller interfaces with SUBSEA, a software simulation of a submarine, developed at ARE Haslar and based on classical six degree of freedom equations and model tank testing data.

The designed autopilot shows a marked improvement in depth keeping over a simple rule based autopilot when conducting a high speed turn.

Safety Instrumentation of Nuclear Plant using Fuzzy Logic
by Lieutenant M. J. Parkins, MSc, RN

The new generation of nuclear power plant is for the first time using software-based systems in safety critical operations with all the inherent safety justification problems. This project investigates the use of Fuzzy Logic for the instrumentation and protection of Nuclear Steam-Raising Plant. The work relies on the modelling of the human operator's internal representation of key plant parameters and his response to their relative magnitudes. It is normal practice for software-based systems of this type to be treated as having only a monitoring function and therefore not requiring safety justification. The ability of the fuzzy-based system to mimic the reasoning processes of the human operator produces an operator aid which gives fast detection of abnormal plant conditions and direct advice to the operator on the correct course of action. Such direct information drives the operator into closing the control loop himself; hence the software is structured in a simple and logical way to allow safety justification to be attempted. The report itself is written in such a way as to be accessible to any nuclear plant operator, particularly those without a background in fuzzy techniques.

The monitoring system resulting from this work is capable of detecting secondary steam leaks based on data from three plant parameters. It gives the operator both warning and diagnostic information several seconds before the first conventional protection system alarm occurs. If future work leads to the inclusion of one additional plant parameter it would enable the monitoring function to be extended to any plant failure.

Condition and Health Monitoring using Crankshaft Torsional Vibration
by Lieutenant-Commander J. C. Orji, BSc, CEng, MIMarE, MNSE, Nigerian Navy.

Monitoring the health and condition of machinery is playing an increasingly important role in predictive and preventive maintenance and hence reducing maintenance costs while increasing machinery reliability. Monitoring crankshaft torsional vibration could provide useful information in this area.

In this project, the suitability of an optical encoder in measuring and analysing engine crankshaft vibration signatures was assessed. The encoder was used to measure amplitudes of vibration of a Perkins 4-cylinder diesel engine. A mathematical model of the diesel engine was developed from which vibration amplitudes for given engine running conditions were calculated. The calculated values were compared with those obtained from encoder measurements as a means of validating the model. The results were encouraging. It was established that the encoder is capable of measuring engine crankshaft torsional vibration, through which differences in the signature patterns and vibration amplitudes can indicate defects and incipient failures. It is recommended that further experimental work be carried out to validate the mathematical model and thus establish methods of using the system for health and condition monitoring of engines.

A Linguistic Self-Organizing Autopilot for Yaw Control of a Warship
by Lieutenant I. M. Jess, MA, MSc, CEng, MIMarE, RN

Course keeping and ship manoeuvring by a helmsman continue to employ ever-reducing manpower resources. Existing autopilots have limitations when operating at low speeds or in high sea states, caused by the complex non-linear process of yaw dynamics. Self-organizing Controllers exhibit attributes

commensurate with the significant demands imposed by yaw control.

This project describes the development of a Self-Organizing Autopilot and its implementation within a real-time test rig. Simulation studies are used to demonstrate the autopilot performance when subjected to a range of ship speeds, course changes, and sea states. Modifications to the autopilot are described which elicit enhanced performance. An improved Self-Organizing Controller design methodology is proposed which replaces exhaustive experimental analysis.

The study concludes that the Self-Organizing Autopilot has significant potential for controlling the yaw dynamics of a warship. Controller limitations are identified, and refinements, which should lead to a more versatile autopilot, are suggested.

Identification and Digital Control of Multivariable Temperature Regulating System

by Lieutenant-Commander J. O. Ogbonna, MSc, Nigerian Navy

The Air-Temperature Control (ATC) system on which this project is based, is centred around a Cold Air Unit (CAU) normally installed in Hunter aircraft as part of the cabin or cockpit pressurizing and air conditioning systems.

A laboratory-based prototype was designed and built by A. J. Fricker in 1982 and he subsequently identified the elements of the multivariable system using frequency domain and time response techniques. The elements identified by this method resulted in 4th and 5th order systems. He subsequently designed a multivariable analogue control scheme for the system. Following this work, an intercooler was added to the system in order to increase the temperature drop across the unit.

The study carried out in this project involved the identification of the dynamic characteristics of the new system incorporating the intercooler, using parameter estimation techniques. Subsequently a digital control scheme for the multivariable system was designed using a general purpose Kemitron computer.

It was found that the system could be effectively modelled using second order models. Ideal pre-compensators and controllers were implemented using a general purpose computer to diagonalize the system and demonstrated good transient response. For comparison purposes, simple steady-state gain pre-compensators were also used to decouple the system interaction components. However, in this case the transient response was found to be poor.

The Effects of Heat Exchangers on the Transient Performance of Intercooled Regenerative Gas Turbines

by Lieutenant-Commander J. E. Jollymore, BEng, MSc, Canadian Forces

The intercooled regenerative gas turbine offers significant potential improvements in steady-state specific fuel consumption and power over the conventional gas turbine. These improvements are due, in the main, to changes in the engine's thermodynamic cycle caused by the addition of heat exchangers. Before this potential may be realized, however, much research is required to determine engine behaviour. To this end, the project investigates the effects of heat exchangers on engine transient performance.

On completion of a literature search, appropriate heat exchangers were designed and an existing software-based simple cycle gas turbine transient simulator was modified to include an intercooler and a recuperator. It was found, using this program, that the engine may experience dangerously high turbine inlet temperatures and spool speeds during the first few seconds of acceleration unless a different control philosophy is used.

In order to determine how the engine might be controlled successfully it is recommended that further research be conducted based on the program written for this project.

Enhancement of Heat Transfer by the use of Transverse Ribs
by Lieutenant-Commander R. W. Jones, BEng, MSc, Canadian Forces

Transverse ribs used as turbulence promoters are found in many high performance industrial applications such as multi-pass turbine blades, advanced gas cooled nuclear reactor fuel bundles, and gas turbine combustors, as a means of improving the heat transfer rate.

This project investigates the forced convection heat transfer characteristics of the external surface of a cylinder incorporating transverse turbulence promoting ribs which models a novel gas turbine combustor. Using a microfoil heat flow sensor the project demonstrated that transverse ribs substantially improved the convective heat transfer coefficient for the cylinder model. The experimental results from the model testing led to a proposal to augment linear cooling in the post secondary zone of a Spey combustor by using transverse ribs.

A Study into the Interaction between Hot Corrosion and Fatigue of Nickel-Based Alloys
by Lieutenant R. G. Hooley, MSc, RN

Marine gas turbine blades are subject to extremely aggressive conditions due to the high temperatures and loading and the presence of corrosive salts in the atmosphere. The salts, primarily sodium sulphate and sodium chloride, enter the turbine through the air intake and the fuel and at the high operating temperatures experienced can lead to the onset of hot corrosion on the turbine blades.

This study investigated the interaction between hot corrosion and fatigue loading on a simple gas turbine blade alloy, Nimonic 80A. The rate of hot corrosion attack on the alloy with no fatigue loading was first determined, and then compared with the rate of attack when subjected to cyclic loading.

The study demonstrated that there is a distinct interaction between hot corrosion and fatigue. Sodium sulphate was found to have a minimal effect on the alloy without fatigue but at fatigue crack initiation sites considerable hot corrosion was observed. When sodium chloride was mixed with the sodium sulphate the pure hot corrosion rate was higher and the fatigue life of the alloy was drastically reduced.

MSc COURSE IN MARITIME DEFENCE TECHNOLOGY (AMDTC 89) PROJECT SUMMARIES

Prediction of the Infra-red Signature of a Ship's Wake
by Lieutenant D. W. Ham, MSc, CEng, MIEE, RN

The increasing interest in the application of the infra-red spectrum to maritime warfare has led to a better appreciation of a warship's infra-red emissions. This project extends the study to include the infra-red signature of a ship's wake. The significant components of the wake are identified and, through examination of these components, the infra-red signature is shown to be composed of reflected sky and sun radiance and self-emitted thermal radiation. Definition of the variables affecting the wake's infra-red characteristics allows suitable modelling algorithms to be proposed and simplifying assumptions to be made. It is concluded that under certain conditions the infra-red signature of a ship's wake can be significant and it is recommended

that the proposed algorithms and assumptions be used as the basis of a computer prediction for further study.

The Hardware Implementation of a Neural Network as a Radar Classifier
by Lieutenant N. A. Long, MSc, AMIEE, RN

Previous research has shown the Multilayer Perceptron model neural network to be suitable for the classification of returns from a high definition radar, such as the Searchwater set used by the Royal Air Force and Royal Navy for Airborne Early Warning.

During the project, returns from this radar set were extracted and digitized using a frame grabber. Training and testing of a neural network on a mainframe computer was carried out using the resulting data. The trained model was then implemented and tested on a high speed digital signal processor (DSP). Results of the classification of each frame were displayed on the host IBM personal computer. Hardware was then developed to extract the relevant information from a video tape recording of the radar output, for presentation directly to the digital signal processor board.

Results have shown that the classification of radar returns using a neural network trained for three classes of targets is feasible in real time. Calculations were made which allowed for the DSP to carry out pre-processing on the raw input data, and for networks classifying larger numbers of targets. This demonstrated that it would be possible to take in and process a frame of data and run a neural network classifying at least nine targets, well within the time taken for the video player to present one frame of information.

It is recommended that the software interface between the hardware and digital signal processor, and the data pre-processing required, should be fully developed, and that full details of the radar interfaces be obtained, to enable an operational system to be constructed.

Minimization of Induced Roll in a Non-Rigid Airship
by Lieutenant S. D. Casboult, BEng, MSc, RAN

Airship technology is progressing towards the use of airships as Maritime Surveillance Platforms. In this application the payload is likely to be a phased array radar, with a requirement to keep roll perturbations to a minimum across the range of operating speeds. The project involved a computer simulation study of induced roll in an airship. Yaw-induced roll and turbulence-induced roll were both investigated. Decoupling pre-compensators were designed to minimize yaw-induced roll across the performance envelope. Roll and yaw autopilots were designed to close the control loop and ascertain whether turbulence-induced roll could be easily controlled.

Results showed that a decoupling pre-compensator is a viable method of reducing yaw-induced roll but that turbulence-induced roll is not easily controlled using classical autopilot design. A lack of roll control authority was evident, meaning that the decoupling pre-compensator could only counter the roll moment induced by a six degree rudder demand. Recommendations include the investigation of added roll control authority through airship design changes and different strategies of autopilot design.

An Evaluation of a Frequency-Domain Beamformer using VHPIC Technology
by Lieutenant P. R. Jagger, MSc, AMIEE, RN

The beamformer function can typically consume 50% of the processing power of a sonar system and a combination of highly effective signal processing devices and efficient algorithms is needed to service the increasingly high throughput rates at this stage. One approach is the utilization of

a VHPIC (Very High Performance Integrated Circuit) within a modular 'processing-element' architecture. This research project involves the design, implementation and performance analysis of a frequency-domain beamforming technique on such a VHPIC, the Plessey BFPAU (Block Floating Point Arithmetic Unit) which was developed under the auspices of the joint MOD/UK Industry VHPIC Demonstrator programme. The frequency-domain beamformer, which uses two-dimensional Fast Fourier Transforms and a zero-padded-FFT beam conversion method, is compared to a time-domain interpolation beamforming technique in the context of current and projected naval sonar applications.

The frequency-domain beamformer is shown to provide a more efficient implementation for a wider range of applications than the literature has suggested in the past. Although not suitable for non-uniform or non-rigid arrays, it offers very accurate beamforming with near theoretical sidelobe levels, lower throughput demands and a reduced hardware expenditure. The main recommendations are to further investigate the application of the frequency-domain implementation for circular array geometries, to study alternative beam conversion algorithms such as the chirp-z transform and the FIR interpolation methods, and, finally, to assess the feasibility of spatial interpolation as a solution to array distortion.

Conical Bearing Target Motion Analysis
by Lieutenant G. M. Chesher, MSc, RAN

This project investigates the target motion analysis problem faced by a ship or submarine using a towed array sonar to estimate the range, course and speed of a target via passive means under conditions of bottom bounce propagation. Conventional TMA algorithms assume that sound rays are received from the horizontal plane containing the towed array; however, under conditions of bottom bounce propagation the flat arrival assumption can induce a serious measurement error in the TMA process.

A three-dimensional view of the ray propagation process is used to produce a motion model which describes the way the observed angle to the target varies with own ship and target motion, for both an arbitrary angle of inclination to the horizontal plane of the sound rays, and propagation from a known bottom depth. The TMA problem was solved by estimating the target track parameters of the motion model from a maximum likelihood estimator based on a non-linear least squares technique. The performance of TMA algorithms based on the flat propagation assumptions, and the three dimensional (conical bearing) formulation, are compared using a monte carlo simulation for varying additive noise and bottom depths. As a baseline for comparison of the algorithms the Cramer-Rao lower bound on the minimum variance of the maximum likelihood estimate of target range is also calculated.

The simulations were conducted 512 times for each scenario of target initial bearing, course, depth, and additive noise. The flat TMA formulation suffered significant errors at practical noise levels, which increased as the depth from which propagation occurred was increased.

The conical bearing formulation, operating under conditions of known depth, was observed to produce either estimates with very small mean range errors and standard deviations equal to the theoretical bound, or, estimates containing large errors which were only marginally better than the flat algorithm. The reason for the two types of performance was found to be the type of ranging manoeuvre employed by ownship; manoeuvres which caused an advantageous tracking geometry were identified. Additionally the robustness of the routine to a 10% error in the estimate of water depth was demonstrated, whilst the solution of propagation from a unknown depth was found to be impractical in the presence of noise.