# MASTER OF SCIENCE
# IN
# APPLIED PHYSICS

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**PERFORMANCE ANALYSIS OF IRTOOL AND COMPARISON TO LWKD MARINE BOUNDARY LAYER PROGRAM**

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This thesis evaluates the ability of the IRTOOL computer simulation program to predict mirages. Using identical input conditions taken from the MAPTIP experiment database, predicted Minimum Mirage Range (MMR) and Maximum Intervision Range (MIVR) from both the IRTOOL and IRBLEM models were extracted and compared with the measurements recorded in the database. By comparison of the algorithms it was found that discrepancies in IRTOOL mirage prediction could be ascribed to the input function for significant ocean wave height, which gave values much greater than measured or used in IRBLEM. For a significant wave height close to the measured value the IRTOOL predictions were in very close agreement with observation and with IRBLEM. IRTOOL predictions were in all cases within 2.7 km and in most cases within 1.3 km of the measurements for all ranges varying from about 7-26 km. The strong temperature gradient predicted by the model within a few meters of the water surface, uncertainties in the measured range, and the variation of 0.8 to 2°C in Air Sea Temperature Difference are sufficient to account for the observed deviations. Differences between predictions of different models are discussed.

**DoD KEY TECHNOLOGY AREAS:** Sensors, Modeling and Simulation

**KEYWORDS:** Refraction, Marine Boundary Layer, Atmosphere, IRTOOL, IRBLEM, Mirage, MAPTIP

**OPTIMIZATION PROCEDURE FOR ELECTRIC PROPULSION ENGINES**

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This thesis addresses the optimization of all types of space electrical propulsion thrusters. From the Langmuir-Irving payload mass fraction formulation, a "dual-optimum" solution is defined, yielding a minimum overall mass for a specified payload consistent with minimum transfer time. This solution fixes the ideal payload mass ratio ($m_{pl}$ / $m_o$) at a value of 0.45, establishing the ratios of effective exhaust velocity ($v$ / $v_c$) and incremental change of vehicle velocity ($\Delta u$ / $v_c$) to characteristic velocity at 0.820 and 0.327 respectively. The characteristic velocity ($v_c$) includes thrust time as well as engine efficiency ($\eta_t$) and specific power ($\alpha$). A range of mass ratios from 0.35 to 0.55 is used in order to allow the system designer some flexibility while remaining close to optimal. Nine examples are presented which demonstrate that mission profiles can be optimized by profile-to-thruster matching. A comprehensive list of currently available electric propulsion engines is provided. This list details important parameters such as

the specific power, which "sizes" an engine in terms of power provided to the thruster at the cost of additional mass. Allowance is also made for a fuel tank mass penalty, and examples show that this can also noticeably influence the optimum design.

**DoD KEY TECHNOLOGY AREAS:** Aerospace Propulsion and Power, Space Vehicles

**KEYWORDS:** Space Propulsion, Electric Propulsion, Ion Engines, Hall Thrusters, Optimum Specific Impulse, Minimum Thrusting Time

### DESIGN AND CONSTRUCTION OF MEDIUM RESOLVING, POWER SCANNING, GRATING SPECTROMETER

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A scanning Ebert-Fastie spectrometer was designed and built for the Optical Physics and Sensors Laboratory of the Naval Postgraduate School. Optical design was done with two commercially available optical design software packages, OSLO LT by Sinclair Optics, Inc., and Optica by Wolfram Research, Inc. Several components for the spectrometer were designed and built at the Naval Postgraduate School Physics Department machine shop to include grating mount, motor mount, entrance and exit slits, gearbox, and spacers. Electronic interfaces included the motor, motor controller, and personal computer to control the diffraction grating angle, and a detector, data logger, lock-in detection system, and personal computer to record data. Data was measured from a Fe hollow cathode source to demonstrate proper operation. The recorded spectral lines were graphed in Microsoft Excel and tentatively identified as those tabulated in the published literature. Future work includes optimization of the resolving power and of the fore optics. Upon completion, the spectrometer will prove to be a very useful instructional aid in the optics and optoelectronics classes taught at the school, and as a medium resolving power visible and near ultraviolet instrument for future student thesis research.

**DoD KEY TECHNOLOGY AREAS:** Chemical and Biological Defense, Sensors

**KEYWORDS:** Spectrometer, Ebert-Fastie, Optics, Detector

### A PROJECTILE FOR A RECTANGULAR BARRELED RAIL GUN

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The Physics Department at the Naval Postgraduate School is developing a concept to overcome the problems that keep present rail guns from being practical weapons. The rails must be replaced often if the rail gun operation is to be continuous. Replacing the rails in present rail gun configurations is time consuming. The Physics Department's design concept uses a rectangular barrel as part of the solution to the problem of replacing the rails. The projectile will require flat surfaces to maintain electrical contact with the flat rails and aerodynamic stabilization because of the lack of angular momentum. This thesis develops one possible model of a projectile for a rectangular barreled rail gun, which could be used to replace the standard five-inch gun found on most warships. The proposed projectile is successfully modeled as a five inch projectile with flat areas planed onto opposite sides and long chord, short span fins attached in a cruciform configuration. The computer programs used to develop the projectile model are included to allow evaluation of alternate configurations.

**DoD KEY TECHNOLOGY AREAS:** Conventional Weapons, Modeling and Simulation

**KEYWORDS:** Projectiles, Rail Guns, Computer Modeling

**QUANTITATIVE ENERGY DISPERSIVE X-RAY SPECTROMETRY USING AN EMISPEC VISION SYSTEM**

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The purpose of this work was to investigate the use of an Emispec Vision System to analyze energy dispersive x-ray spectra (EDS) obtained with the Topcon 002B transmission electron microscope (TEM) in the Materials Science Laboratory at the Naval Postgraduate School.

A series of tests performed with a standard NiO sample revealed that the TEM column and EDS detector were operating in a satisfactory fashion. NiO spectra acquired with different sample tilt-angles were used to test the Emispec software. An improved setup configuration, in which accurate quantification is obtained with the sample at zero tilt-angle, was developed.

Quantification tests performed with $TiO_2$, Cu-$Al_2O_3$ and alumina-YAG (with 2.5% $TiO_2$) samples confirmed the accuracy of the new software setup. Line profiles across the alumina-YAG interfaces were also recorded to verify the performance of the Emispec system for spectrum profile acquisition and to investigate the Ti distribution at the interface of the alumina-YAG heat-treated sample.

**DoD KEY TECHNOLOGY AREA:** Materials, Processes, and Structures

**KEYWORDS:** Transmission Electron Microscopy, Energy Dispersive X-Ray Spectra, EDS Quantitative Analysis

**HIGH SPEED MARINE CRAFT THREAT: BUOYANCY AND STABILITY REQUIREMENTS FOR A SUB-LAUNCHED WEAPON SYSTEM**

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Military intelligence has researched various scenarios in which the submarine is the only platform available to engage hostile waterborne infiltration forces. Torpedoes are meant for large ships and cruise missiles are strategic weapons not to be wasted on small craft. Therefore, the submarine does not have a weapons capability to engage and destroy high-speed marine craft (HSMC) that would be used for coastal infiltration.

The most practical scenario would utilize a torpedo stow for a weapon system that would be tube launched, thus ensuring the maximum cruise missile capability of the submarine with a minimal sacrifice to its anti-surface and anti-submarine capabilities. The maintaining of submarine stealth will be paramount, therefore, an off-hull launcher is desired. The weapon needs to be highly discriminative due to high shipping traffic in the coastal environment. In all, the major factors associated with the design and employment of a sub-launched weapon system for engaging HSMC are the threat, the missile, the launcher and the deployment method.

In a hostile coastal environment, there are numerous targets ranging from surface threats to air threats. Missile design is dependent on the threat and can be varied for different scenarios. However, the launcher and deployment of a tube launched weapon system are only restricted by the dimensions of the torpedo tube and the buoyancy and stability of the designed launcher. These parameters can be quantified and

modeled. This thesis focused on designing a weapon system, SEABAT, to meet the basic buoyancy and stability requirements. The results of the SEABAT design prove its feasibility as a torpedo tube launched weapon system.

**DoD KEY TECHNOLOGY AREA:** Conventional Weapons

**KEYWORDS:** High Speed Marine Craft, Buoyancy, Stability, Submarine Launched Weapon System

### OPERATION AND CALIBRATION OF THE NPS ULTRAVIOLET IMAGING SPECTROMETER (NUVIS) IN THE DETECTION OF SULFUR DIOXIDE PLUMES

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The Naval Postgraduate School's Ultraviolet Imaging Spectrometer (NUVIS) is a hyperspectral sensor with a spectral response of 300 to 375 nanometers. This thesis research concentrates on the operation and calibration of NUVIS in the detection of effluent sulfur dioxide ($SO_2$) plumes. NUVIS is capable of detecting and quantifying $SO_2$ emissions in the form of effluent smokestack plumes by exploiting $SO_2$'s unique UV absorption signature. Laboratory comparison UV spectra of $SO_2$ were recorded and used to calculate curves of growth for four different $SO_2$ spectral features. Laboratory results were employed to analyze field data taken of a coal-burning power plant. Analysis of this plume data yielded a mean plume $SO_2$ mixing ratio of 365 ± 200 ppm, in agreement with the *in situ* stack value of 400 ppm. Further assessment of NUVIS indicates that its lower limit for $SO_2$ detection in typical field applications is approximately 70 ppm.

**DoD KEY TECHNOLOGY AREAS:** Chemical and Biological Defense, Environmental Quality, Sensors

**KEYWORDS:** Ultraviolet, Hyperspectral, Spectral Imaging, Spectrometer, Sulfur Dioxide, Pollution, Remote Sensing, Environmental Monitoring

### EVALUATION OF RANGE COMPENSATION IN THERMAL IMAGING OF SHIPS USING THE EOPACE DATA BASE

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An ever-present problem in analyzing thermal images for target signatures is the influence of atmospheric effects in the signature observed at significant range. The compensation for these effects, mostly atmospheric absorption and scattering and path radiance requires accurate knowledge of the meteorological parameters for the area involved at the time of the measurements.

Based both on infrared image files taken during the Electro-Optical Propagation Assessment in Coastal Environments (EOPACE) experiment together with the EOPACE environmental data base and on the SeaRad propagation code to generate radiance, a range compensation algorithm is proposed in this thesis. Applying SeaRad output adjusted for the sky path radiance, an 11 by 11 matrix of the apparent sea temperatures is constructed in which each row corresponds to a different zenith angle and therefore range, and each column to a different sea apparent black body temperature. By interpolation all sea pixels in the image are range compensated. The ship pixels are range compensated by imposing continuity in the sea ship interface. The magnitude of scene temperature correction required is of the order of -2.3 ± 1.7 °C which is comparable to the precision of the recorded data.

**DoD KEY TECHNOLOGY AREAS:** Battlespace Environments, Sensors, Modeling and Simulation

**KEYWORDS:** Infrared Radiation, Radiance, Atmospheric Propagation, Range Compensation, Thermal Imaging

**AN ANALYSIS OF RE-ACQUISITION AND IDENTIFCATION SENSORS FOR VERY SHALLOW WATER MINE COUNTERMEASURES (VSW MCM) WARFARE**

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The Naval concepts Operational Maneuver from the Sea (OMFTS) and Ship to Objective Maneuver (STOM) will not succeed unless mines and obstacles can be located, identified and cleared from the amphibious approaches. The US Navy's Mine Warfare Plan and the Navy Investment Strategy for Development of Unmanned Underwater Vehicle Systems in Support of naval Very Shallow Water and Explosive Ordnance Disposal Mine Countermeasures Missions have defined specific strategies for achieving a very shallow water mine clearance capability. This thesis examines the potential for various technologies (sensors) to support very shallow water minefield clearance in the re-acquisition and identification of mines and obstacles. First, the mission is defined and current capabilities are reviewed. Second the requirements for the Very Shallow Water Mine Countermeasures mission are examined from the point of view of a notional concept of operations, the operating environment, and required performance characteristics, and, criteria are developed to evaluate potential detection and identification systems. Finally, detection and identification technologies are examined and evaluated against derived criteria. The results are two tables that can be used together as a tool to determine optimum combinations of sensors based upon mission priorities (precise identification, object location, neutralization, area survey) and vehicle capability (incremental energy available for sensors, payload capacity, mission portability, mission duration).

**DOD KEY TECHNOLOGY AREAS:** Sensors, Surface/Under Surface Vehicles - Ships and Watercraft, Conventional Weapons, Other (Mine Countermeasures)

**KEYWORDS:** Electro Optics, VSW MCM, EOD, AUV, STOM, OMFTS, Mine Hunting, UUV