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Energy Academic Group Compilation of Abstracts 2012-2016

Monterey, California; Naval Postgraduate School

Energy Academic Group

Compilation of Abstracts

Unrestricted Theses, Dissertations, and Capstone Project Reports

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This report highlights the breadth of energy-related student research at NPS and reinforces the importance of energy as an integral aspect of today's Naval enterprise. The abstracts provided are from theses and a capstone project report completed by December 2012 - March 2016 graduates.

The increasing importance of energy has been strongly emphasized by leadership at all levels in the executive and legislative branches of government, and specifically by the Secretary of the Navy, the Chief of Naval Operations (CNO), and Fleet and Shore commanders. The CNO has requested a Navy Energy Strategy that treats energy as a strategic resource.

Issues and problems related to energy occur at the intersection of multiple disciplines, and their solutions therefore require interdisciplinary knowledge and actions. In response, the Naval Postgraduate School has established the Energy Academic Group (EAG). The EAG will develop and maintain NPS as a Navy Center of Excellence for Energy Graduate Education and Research.

The three pillars of the EAG are education, research, and outreach:

Education: NPS Defense Energy Programs are interdisciplinary, shared by organizational units throughout the campus. Over 49 NPS faculty members from all four schools are affiliated with the Energy program, actively participating in Energy graduate education, Energy executive education, and Energy research. Four graduate degree programs at NPS offer Energy specialty tracks:

- Operations Analysis
- Naval/Mechanical Engineering
- Electronic Systems Engineering
- Financial Management

Research: Energy research at the Naval Postgraduate School (NPS) is highly diverse, reflecting the diverse interests of our highly capable faculty and students. A wide range of subject areas are covered by NPS energy research, including basic sciences, engineering, operations and analysis, and business. There is also an increasing amount of work that is cross disciplinary, involving faculty and students from multiple subject areas in solving the Navy, Marine Corps and DOD critical energy needs.

Outreach: NPS's academic programs in defense energy are supplemented by the NPS Defense Energy Seminar, which was launched in 2008 and provides a forum for leading voices within the field, practitioners, and other defense-energy influencers. EAG also offers a five-day course, "Leading Innovation with an Energy Application Focus."

For more information, please contact the following individuals or visit our website at: http://www.nps.edu/Academics/OtherPrograms/Energy/.

Dr. Daniel Nussbaum, Chair
mailto:danussba@nps.edu

Alan Howard, Deputy Chair
mailto:arhoward@nps.edu

DECEMBER 2012

Graduate School of Business and Public Policy

MAKING THE SURFACE FLEET GREEN: THE DOTMLPF, POLICY, AND COST IMPLICATIONS OF USING BIOFUEL IN SURFACE SHIPS

Calvin S. Beads III–Lieutenant, United States Navy
Master of Business Administration
Lead Advisor: Daniel Nussbaum, Graduate School of Operational and Information Sciences
Support Advisor: William Fast, Graduate School of Business and Public Policy

One of the goals of the Department of the Navy's (DON) alternative energy initiative is to reduce the Navy's dependence on fossil fuel. This project uses DOTMLPF criteria to measure the impact of biofuel use on the Surface Fleet. It provides analysis and recommendations for using replacement drop-in biofuels onboard surface ships based on materiel, maintenance, training, infrastructure, logistics, policy, and cost implications. http://calhoun.nps.edu/handle/10945/27792

KEYWORDS: biofuel, alternative energy, DOTMLPF, surface warfare, petroleum, F-76, HRD-76, drop-in replacement biofuel

AN ANALYSIS OF EFFECT OF WATER RESOURCES CONSTRAINT ON ENERGY PRODUCTION IN TURKEY

Timur Tilki–First Lieutenant, Turkish Army
Huseyin Karakas–First Lieutenant, Turkish Air Force
Master of Business Administration
Lead Advisor: Geraldo Ferrer, Graduate School of Business and Public Policy
Support Advisor: John Khawam, Graduate School of Business and Public Policy

The purpose of this study is to measure the influence of Turkey's water resources on energy production, considering growing demand in the future. In our study, we will examine water usage in electricity generation in different types of thermal power plants. The project will assess the available water resources in the future, the proportion of these resources that will be allocated to energy production, and the increasing energy demand for specific years in the future. Additionally, we will compute the number of thermal power plants and types to meet future energy demands by building an optimization model. Also, the project will include analysis of optimization model results in terms of correlation between water and energy. http://calhoun.nps.edu/handle/10945/27851

KEYWORDS: water resources, renewable, non-renewable, energy resources, power plants, energy production, electricity generation, Turkey

COMPARATIVE COST-BENEFIT ANALYSIS OF RENEWABLE ENERGY RESOURCE TRADE OFFS FOR MILITARY INSTALLATIONS
Jon Patrick McFaul–Major, United States Marine Corps
Paulina Sias Rojas–Major, United States Marine Corps
Master of Business Administration
Advisor: Geraldo Ferrer, Graduate School of Business and Public Policy
Second Reader: Nicholas Dew, Graduate School of Business and Public Policy

The purpose of this research is to analyze the framework the Department of Defense (DOD) is utilizing concerning energy and energy efficiency initiatives across military installations to determine the United States Marine Corps (USMC) and DOD's potential savings by managing investments in renewable energy (in all installations) as a portfolio of opportunities that maximizes benefits and sustainability. In addition, this study evaluates renewable energy resource technologies that have the best long-term economic stability and the least challenges for future growth on military installations. Also, it describes how the challenges of human behavior, budget cuts, financing approaches, and regulations may play a big part in harnessing the optimal benefit from renewable energy resources. This study analyzes how comprehensive knowledge management, in combination with renewable energy efforts across installations, can capitalize DOD cost savings for long-term stability. This research recommends DOD take a comprehensive strategy approach through risk management analysis, information sharing, and better business practices. http://calhoun.nps.edu/handle/10945/27867

KEYWORDS: renewable energy, Marine Corps military installations, energy security, net zero energy initiative, energy financing approaches, cost benefit analysis

Defense Analysis

THE SILENT REVOLUTION WITHIN NATO LOGISTICS: A STUDY IN AFGHANISTAN FUEL AND FUTURE APPLICATIONS
Michael J. Evans–Major, United States Air Force
Stephen W. Masternak–Captain, United States Air Force
Master of Science in Defense Analysis
Co-Advisor: Keenan Yoho, Department of Operations and Logistics Management
Co-Advisor: E. Cory Yoder, Department of Acquisition Management
Second Reader: Brian Greenshields, Department of Defense Analysis
Second Reader: Frank Giordano, Department of Defense Analysis

This thesis captures a history of the North Atlantic Treaty Organization (NATO) logistics fuel operation in Afghanistan and considers its lessons for the broader logistics community. The research focuses on a small group of individuals and how they came to supply over three million liters of fuel daily to Afghanistan with very little upfront investment from the International Security Assistance Force (ISAF) nations. The thesis describes how these individuals managed NATO fuel operations outside of traditional agencies like the NATO Support Agency (NSPA) and the worldwide U.S. Defense Logistics Agency (DLA) Energy. In addition, this thesis examines NATO's operation in Afghanistan as compared to similar historical examples of large-scale coalition fuel efforts over long lines of communication. These historical case studies assist in framing the context of NATO logisticians' accomplishments and the level of risk they accepted in supplying fuel to the

NATO-led ISAF mission. Finally, the NATO case study provides a model for coalition support in a time when nations are unwilling or unable to provide logistic support to their forces. http://calhoun.nps.edu/handle/10945/27827

KEYWORDS: fuel, class III, U.S. fuel operations, NATO, logistics, Defense Logistics Agency Energy, DLAE, NATO Support Agency, NSPA, ISAF, coalition logistics, multinational logistics, Afghanistan logistics, basic ordering agreement, BOA, contract cogistics, Logistics Civil Augmentation Program, LOGCAP, price per liter, PPL, fully burdened cost of fuel, FBCF

Electrical and Computer Engineering

MODELING AND SIMULATION OF A DUAL-JUNCTION CIGS SOLAR CELL USING SILVACO ATLAS

Konstantinos Fotis–Lieutenant, Hellenic Navy
Electrical Engineer
Master of Science in Electrical Engineering
Advisor: Sherif Michael, Department of Electrical and Computer Engineering
Second Reader: Todd Weatherford, Department of Electrical and Computer Engineering

This thesis investigates the potential of designing a dual junction Copper Indium Gallium Selenide (CIGS) photovoltaic cell. Research into implementing a dual-junction solar cell, using a CIGS bottom cell and different thin-film designs as a top cell, was conducted in order to increase the current record efficiency of 20.3% for a single CIGS cell. This was accomplished through modeling and simulation using Silvaco ATLAS, an advanced virtual wafer-fabrication tool. A Silvaco ATLAS model of a single CIGS cell was created by utilizing solar cell parameters (such as layer thicknesses, gallium ratio, doping levels, and materials properties) that have been previously documented in other works, such as previous NPS theses. After the individual CIGS solar cells were built, a dual-junction cell was created by adding the layers of another CIGS solar cell, whose parameters (layers thicknesses, Ga ratio) was varied, to produce an optimum efficiency of 24%. This is a promising approach to producing a multi-junction CIGS cell with record efficiency. http://calhoun.nps.edu/handle/10945/27831

KEYWORDS: solar cell, CIGS, photovoltaic, multi-junction, Silvaco, Atlas, I-V Curve, modeling, simulation, development

EXTENDING THE ENDURANCE OF SMALL UNMANNED AERIAL VEHICLES USING ADVANCED FLEXIBLE SOLAR CELLS

Christopher R. Gromadski–Captain, United States Marine Corps
Master of Science in Electrical Engineering
Advisor: Sherif Michael, Department of Electrical and Computer Engineering
Second Reader: Rudolf Panholzer, Department of Space Systems Engineering

Due to battery life, most currently fielded small unmanned aerial vehicles (SUAV) have flight times limited to 90 minutes. They are often forced to work in teams of multiple crafts to provide tactical level units with continuous observation of the battlefield. Continuous operations place a strain on logistics trains by requiring either more batteries or fuel to support recharging. Prior theses have examined the ability of solar cells to extend the flight endurance and capabilities of SUAV during peak sunlight conditions. This research demonstrated the viability of augmenting the onboard power

supply with advanced thin-film photovoltaic (TFPV) cells made of copper-indium-gallium selenide (CIGS) over a longer period of time. The additional source of power will reduce, at times even eliminate, the demand on the lithium polymer batteries of a Raven SUAV as sunlight conditions change throughout the day. All components used in construction were commercially available, including foam wings that closely resembled the airfoil of a Raven SUAV, with increased surface area. The laboratory tests used standard operating procedures from the operator's manual, and input from the training community, to accurately simulate flight conditions and field use. This research demonstrates that for minimal cost in money and weight, the degraded components and non-ideal sunlight conditions still provide a significant improvement over the original system. The approach is relevant as this system can be used in austere combat zones which require results in conditions that are rarely ideal. Additionally, the research applied projections to the capabilities of the augmenting circuitry on unmodified Raven wings and Puma SUAVs. http://calhoun.nps.edu/handle/10945/27836

KEYWORDS: solar power, thin solar cells, CIGS, UAV, Raven, expeditionary energy

THE MODIFICATION OF HOMER SOFTWARE APPLICATION TO PROVIDE THE UNITED STATES MARINE CORPS WITH AN ENERGY PLANNING TOOL

Alexis R. Harvey–Captain, United States Marine Corps
Master of Science in Electrical Engineering
Advisor: Sherif Michael, Department of Electrical and Computer Engineering
Co-Advisor: Daniel Nussbaum, Department of Operations Research

The Marine Corps is getting back to its expeditionary roots, becoming lighter, leaner, and conversely ever more dependent on power. Until recently, expeditionary power planning had been an afterthought in the Marine Corps. HOMER (Hybrid Optimization Model for Electric Renewables) is a software tool that will enable Logistics Marines to conduct detailed planning to provide efficient expeditionary power. The focus of this thesis is the addition of Marine Corps systems into HOMER. Specific investigations include an analysis of SPACES compared to a control system and rapid-discharge heat testing of lithium ion batteries. Results include performance specifications for SPACES entry into HOMER and partial validation of the use of the Kinetic Battery Model for Lithium Ion Batteries. http://calhoun.nps.edu/handle/10945/27842

KEYWORDS: HOMER, model, logistics, solar array, SPACES, kinetic battery model, lithium ion battery

UTILIZING MAXIMUM POWER POINT TRACKERS IN PARALLEL TO MAXIMIZE THE POWER OUTPUT OF A SOLAR (PHOTOVOLTAIC) ARRAY

Christopher A. Stephenson–Captain, United States Marine Corps
Master of Science in Electrical Engineering
Advisor: Sherif Michael, Department of Electrical and Computer Engineering
Second Reader: Robert W. Ashton, Department of Electrical and Computer Engineering

It is common when optimizing a photovoltaic (PV) system to use a maximum power point tracker (MPPT) to increase the power output of the solar array. Currently, most military applications that utilize solar energy omit or use only a single MPPT per PV system. The focus of this research was to quantify the expected benefits of using multiple MPPTs within a PV system based on current technologies and summarize what may be possible in the near future. In this thesis, the advertised 5-8% gains in efficiency claimed by manufacturers of the multiple MPPT approach were tested, and a set of generalized recommendations concerning which applications may benefit from this distributed

approach, and which ones may not, were sought. The primary benefit of utilizing multiple MPPTs is that independently operating panels within a solar array could possibly increase the overall reliability and resiliency of the entire PV system and potentially allow for solar applications to be used in particularly harsh and dynamic environments with increased confidence. Additionally, using multiple, smaller MPPTs could decrease the overall array dimensions; this would save space, reduce weight, and lower costs. http://calhoun.nps.edu/handle/10945/27907

KEYWORDS: solar efficiency, maximum power point tracker, micro-inverter, micro-converter, power optimizer, distributed solar array

DESIGN OF A MAXIMUM POWER POINT TRACKER WITH SIMULATION, ANALYSIS, AND COMPARISON OF ALGORITHMS

Jeff Wurz–Civilian, Department of the Navy
Master of Science in Electrical Engineering
Advisor: Robert Ashton, Department of Electrical and Computer Engineering
Second Reader: Vladimir Dobrokhodov, Department of Mechanical and Aerospace Engineering

In this thesis, the advantages of three different maximum power point tracking (MPPT) algorithms are investigated. By simulation, the performance and efficiency of these algorithms were analyzed. By using MATLAB's SimPowerSystems block set, we created the model comprised of a Kyocera KD135GX-LP solar panel powering a buck converter controlled by the MPPT algorithms driving a resistive load. The main objective was to track the maximum power point (MPP) of the solar array by modulating the buck converter's duty cycle, thereby, optimizing the power output of the panel. The three algorithms' performances were on par with other real world tests of these algorithms as seen in other published work. The Perturb and Observe (P&O) algorithm performed with a higher overall efficiency and was able to track the MPP quickly while the Incremental Conductance (InC) algorithm had similar performance but required more intensive calculations. The analysis of these algorithms led to a greater understanding of where the inefficiencies of this type of system are located, allowing improvement in future work on this subject. http://calhoun.nps.edu/handle/10945/27924

KEYWORDS: MPPT, maximum power point tracker, buck converter, solar array, simulation, MATLAB, incremental conductance, perturb and observe

Information Sciences

MODELING AND ASSESSMENT OF ALTERNATIVE COOLING METHODS OF THE COMBAT OPERATION CENTER

Matthew S. Moreno–Captain, United States Marine Corps
Master of Science in Information Technology Management
Advisor: Man-Tak Shing, Department of Computer Science
Second Reader: Albert Barreto, Department of Information Sciences

The Marine Corps' Combat Operations Center provides formidable situational awareness and command and control capability using a robust mobile data center. This capability incurs a cost in fuel and restricted mobility due to the size and weight of the cooling and electrical generation. Enhancing the energy efficiency through alternative cooling methods will enhance the Marine Corps'

tactical flexibility on the battlefield. In both Iraq and Afghanistan, the Improvised Explosive Device threat is of grave concern. Reducing the frequency of fuel convoys may reduce the associated casualties that result. In this research, a model was created to predict the potential reduction in fuel consumption by using alternative methods of cooling. The model considers all the sources of heat load introduced into the Combat Operations Center environment and estimates the amount of electricity required to maintain a set point temperature. An alternative method of cooling is introduced to determine whether it has the potential to reduce fuel consumption. A substantive increase in efficiency indicates further research has merit. The model offers an analytical method for exploring alternative cooling methods that may be used either individually or in concert to reduce the fuel required by the Combat Operations Center. http://calhoun.nps.edu/handle/10945/27875

KEYWORDS: modeling, efficiency, COC tactical data processing

Physics

GAAS/INAS MULTI QUANTUM WELL SOLAR CELL

Evangelos Koletsios–Hellenic Navy
Master of Science in Applied Physics
Advisor: Sherif Michael, Department of Electrical and Computer Engineering
Co-Advisor: Gamani Karunasiri, Department of Physics

In this thesis, Silvaco software is used to analyze a solar-cell structure containing quantum wells. Successful results will allow the exploitation of most of the advantages of quantum-well systems. This challenging research represents the first time Silvaco simulation software has been used in the design of such a solar cell. This research is promising because of its potential to increase the attainable energy efficiency of solar photon conversion, due to tunable bandgaps, that can absorb most of the solar spectrum, which conventional singlelayer crystalline solar cells cannot do. The ultimate goal is the assembly of a quantum-well layer to achieve high efficiency. A theoretical infinite-layer cell can reach an efficiency of 86% (constrained by thermodynamical limits). Quantum wells can reach 65%+ when a multilayer cell has reached 49% and are relatively expensive to fabricate.
http://calhoun.nps.edu/handle/10945/27856

KEYWORDS: Robots, Robotics, Amphibious Vehicles, Mobility, Surf-zone, Dynamic Model, Kinematic Model, Vicon Motion Capture, Gazebo, Ros, Ubuntu, Simulation, Lagrangian Mechanics

Space Systems

SPACE-BASED SOLAR POWER SYSTEM ARCHITECTURE

Brian C. Busch–Captain, United States Air Force
Master of Science in Space Systems Operations
Advisor: Mark Rhoades, Department of Systems Engineering
Second Reader: Dan Bursch, Space Systems Academic Group

Fossil fuels are, by their very nature, finite resources. There are, however, numerous renewable energy sources that should be taken advantage of. One of the most abundant is also the most difficult to produce on Earth—solar energy. This thesis explores the feasibility of a space-based solar

power satellite. The thesis focuses specifically on the satellite design as opposed to the end-to-end design to include the ground segment. It explores the potential orbits for such a satellite to operate from and ultimately concludes that a geostationary orbit is the only logical location for an operational orbit. This thesis also focuses on two segments of the spacecraft: the solar array and the power transmission payload. The solar array area was calculated using the current best theoretical solar cells and assumed a 1 GW transmission power. Finally, this thesis explored which transmission payload to recommend for an operational system, concluding that a laser system is the most efficient use of space and weight. The final portion of this thesis was to examine the business case. Based on the design in this thesis, spacebased solar power cannot compete with fossil fuels and likely will not for the foreseeable future. http://calhoun.nps.edu/handle/10945/27802

KEYWORDS: space, solar power, transmission, satellite, architecture study

MARCH 2013

Graduate School of Business and Public Policy

THE ELECTROMAGNETIC IMPACT OF WIND TURBINES

Gregory Sasarita, GS-13, U.S. Army Electronic Proving Ground
Charles R. Wright, GS-13, U.S. Army Missile Command
Master of Program Management
Lead Advisor: David F. Matthews, Graduate School of Business and Public Policy
Support Advisor: Joseph T. Schulte, Chief, Joint Interoperability Test Command

The objective of this project was to investigate the impact that a wind turbine can have on the electromagnetic environment that affects communication systems. The power generation process in a wind turbine has the potential to create radio frequency (RF) emissions, and the tower/blades can reflect RF signals, which can negatively impact RF communication systems. This project involved measuring the RF environment before and after the wind turbine was constructed. RF signals between 2 MHz and 18 GHz were transmitted towards the location of the wind turbine using directional antennas while taking receive-signal-level (RSL) measurements at different distances from the turbine. This was done after the wind turbine was fully operational. The effects of the wind turbine on the RF environment were based on measurements taken before and after the turbine was constructed. Methods to mitigate effects encountered were explored. The effects that wind turbines have on the electromagnetic environment and referenced communication systems were documented in detail, along with suggestions on how to mitigate the effects. http://calhoun.nps.edu/handle/10945/32896

KEYWORDS: wind turbine, renewable energy, RF emissions, interference

FULLY BURDENED COST OF ENERGY ANALYSIS: A MODEL FOR MARINE CORPS SYSTEMS

Richard H. Witt III–Major, United States Marine Corps
Christopher E. Larson–Captain, United States Marine Corps
Master of Science in Management
Advisor: Simona L. Tick, Graduate School of Business and Public Policy
Second Reader: Daniel A. Nussbaum, Graduate School of Operational and Information Sciences

This thesis develops an operational model for estimating the fully burdened cost of energy (FBCEnergy) for the United States Marine Corps (USMC). Marine Corps Systems Command (MARCORSYSCOM) is responsible for the acquisition of ground equipment for the USMC. While USMC ground equipment is primarily dependent on fossil-based fuel, recent shifts in Department of Defense (DoD) acquisitions policy require consideration of all energy consumption, not just fuel.

This thesis uses a stochastic approach and Monte Carlo simulations to develop an operational,

easy-to-adjust model for estimating the FBCEnergy for the USMC while considering the commodity cost of fuel; fuel delivery operation and support costs; fuel delivery asset depreciation; direct fuel infrastructure; indirect fuel infrastructure; environmental cost; and other platform unique costs such as force protection or regulatory compliance. The model and main findings of this thesis can be used in any future analysis of alternatives (AoA) performed before the acquisition of new weapon systems. http://calhoun.nps.edu/handle/10945/32920

KEYWORDS: analysis of alternatives, fully burdened cost of fuel, fully burdened cost of energy, assured delivery price, scenario route apportionment, Monte Carlo simulation

Electrical and Computer Engineering

PEAK POWER CONTROL WITH AN ENERGY MANAGEMENT SYSTEM

Nathan J. Peck–Lieutenant, United States Navy
Master of Science in Electrical Engineering
Advisor: Giovanna Oriti, Department of Electrical and Computer Engineering
Co-Advisor: Alexander L. Julian, Department of Electrical and Computer Engineering

The Department of Defense (DOD) is researching methods to enhance energy security and reduce energy costs. The energy security of DOD installations relies on the commercial electricity grid. One method being considered to improve energy security and reduce energy costs is the use of microgrids that include combinations of energy storage, energy sources, critical loads, and non-critical loads. A microgrid's power demand and the benefits of a microgrid integrated with a power electronics-enabled energy management system (EMS) is investigated in this thesis. The power demand of a single family household is analyzed. The peak power demand of the single family household displays the drawbacks of peak power demand on the commercial electricity grid and the installations receiving power from it. Drawbacks include reduced energy security due to blackouts and increased cost as a result of meeting the peak demand. One benefit of an EMS is its ability to island or continue supplying power to critical loads when the commercial electricity grid is lost. A second benefit is reduced power demand on the commercial electricity grid during peak power demand or on distributed resources (DR) while islanded by performing peak power control. The performance of peak power control by an EMS is demonstrated using a Simulink model and an experimental laboratory setup. The Simulink model and EMS functionality are validated with the laboratory experiments. The Simulink model is then used to demonstrate the reduction in peak power demand on the commercial electricity grid using an EMS on more complex loads such as motors and diode rectifiers. The Simulink model is also used to compare the power demand on the commercial electricity grid with and without the EMS. http://calhoun.nps.edu/handle/10945/32884

KEYWORDS: energy management system, microgrid

Mechanical Engineering

EXPERIMENTAL AND COMPUTATIONAL FLUID DYNAMIC ANALYSIS OF AXIAL-FLOW HYDRODYNAMIC POWER TURBINE

Grant T. Bryan–Lieutenant, United States Navy
Master of Science in Mechanical Engineering
Advisor: Young W. Kwon, Department of Mechanical and Aerospace Engineering
Co-Advisor: Maximilian F. Platzer, Department of Mechanical and Aerospace Engineering

Thorough analysis of drag and power characteristics of hydrodynamic power turbines is necessary for the efficient extraction of energy available at sea. In an effort to obtain these characteristics for a three-bladed, axial-flow hydroturbine used to provide electric power on small sailing vessels, a load cell and voltage measuring system was installed on a carriage in a towing tank for analysis across a speed range of 0.5 to 1.8 m/s. A high-speed camera was used to determine the precise carriage speed and the rotational speed of the turbine rotor. For validation of concept, two thin flat plates were analyzed using the same drag force measuring system in the tow tank to compare experimentally determined drag coefficients with known literature values.

Results are shown for the drag force experienced by the flat plates and both the non-rotating and the rotating turbine configurations. Additional results are shown for the turbine's power generation capabilities at rotational speeds between 90 and 500 RPMs. Using computational fluid dynamics for the rectangular flat plate and non-rotational turbine configuration, the experimental and computational results for the drag force characteristics were compared. http://calhoun.nps.edu/handle/10945/32801

KEYWORDS: hydropower turbine, hydrodynamic power generations, experimental towing tank analysis of hydroturbine, computational fluid dynamics of 3-bladed rotor for underwater turbine

Security Studies

AN ENERGY BRIDGE TOO FAR? UNCONVENTIONAL NATURAL GAS INNOVATIONS AND EURASIA'S ENERGY BRIDGE

Wayne J. Dahl Jr.–Captain, United States Army
Master of Arts in Security Studies (Europe and Eurasia)
Advisor: Victoria Clement, Department of National Security Affairs
Co-Advisor: Mikhail Tsypkin, Department of National Security Affairs

Energy security has become a key watchword in defining the contemporary security landscape. Although the 1973 oil crisis is likely the most significant energy dispute in modern history, energy conflicts continue to impact nations and citizens around the world. Several energy disputes with Russia in the first decade of the twenty-first century serve as poignant examples of contemporary energy insecurity. The 2006 Russia-Ukraine gas disagreement halted the delivery of 100 million cubic meters of gas to Europe; in 2007, the Russian–Belarus energy clash direly affected Germany's economy. Subsequently, Ukraine siphoned gas from its pipeline to Europe in an attempt to hold

European households hostage during a row with Russia over gas prices in 2009. However, unconventional natural gas innovations, such as shale gas and liquefied natural gas (LNG), are dynamically altering the energy security relationships between Russia, the former Soviet republics, and Europe. This thesis will utilize a comparative study of the contemporary natural gas pipeline market and current unconventional gas market to analyze the ramifications both markets have on European and Eurasian energy security, future prospects for expansions, and possible sources of contention within both frameworks, which will lead to an examination of future energy security policy implications. http://calhoun.nps.edu/handle/10945/32807

KEYWORDS: energy, energy security, liquefied natural gas, shale gas, natural gas, pipelines, European Union, Russia, Central Asia, Caspian Basin

Systems Engineering

HAWAII ALGAL BIOFUEL
Cohort 311-113A, Team HNAABS
Master of Science in Systems Engineering and Master of Science in Engineering Systems
Advisor: David H Olwell, Department of Systems Engineering
Second Reader: Joseph W Sweeney, Department of Systems Engineering

This report investigated the feasibility and affordability of producing algae-derived biofuel in Hawaii for military aviation. The authors evaluated methods for cultivating algae, investigated the processes necessary to locally refine bio-oil into bio-kerosene, researched the environmental impacts of cultivation and refinement facilities in Hawaii, and studied the resultant cost-per-gallon of bio-kerosene production. Based on the current state of technology and the proposed system of systems architecture, this report estimated that bio-kerosene could be produced for $8.00-22.87/gal, indicating that although this system was technically feasible, is was unaffordable at current fuel prices without ongoing subsidies or further technical innovation.
http://calhoun.nps.edu/handle/10945/32891

KEYWORDS: biofuel, algal oil, green crude, bio-kerosene, Hawaii, energy security, naval aviation fuel

ALGAE-BASED BIOFUEL DISTRIBUTION SYSTEM TO SERVICE THE DEPARTMENT OF DEFENSE IN HAWAII
Cohort 311-1130, Team Biofuels
Master of Science in Systems Engineering and Master of Science in Engineering Systems
Advisor: Brigitte T. Kwinn, Department of Systems Engineering
Advisor: Mark M. Rhoades, Department of Systems Engineering

The most effective distribution system, capable of delivering 42.9 million gallons of biofuel annually to the Department of Defense aviation assets in the state of Hawaii, consists of a combination of pipeline and trucks. A tailored systems engineering process using an analytical hierarchy process assessed stakeholders' requirements with quantifiable metrics and used CORE to develop a functional architecture to trace these needs. The modeling software ExtendSim was used

to simulate various alternatives of a distribution system comprised of pipeline and/or trucks to deliver a required capacity of a pre-mixed biofuel blend. Environmental risks of the system were assessed, and a master logic diagram was used to identify ways to manage risk. Based on this analysis, the capabilities and benefits of this combination system outweigh the potential risks associated with its operation. An analysis of alternatives confirmed that in terms of performance and cost, the most efficient distribution system takes place in two stages. First is the transportation of biofuel from the refinery to the Red Hill Storage Facility via the pipeline currently in place. From this point, trucks load the biofuel at the pumping station to continue delivery to the customers.
http://calhoun.nps.edu/handle/10945/32893

KEYWORDS: systems engineering, biofuel distribution, AHP, functional architecture

JUNE 2013

Graduate School of Business and Public Policy

USING PHOTOVOLTAIC (PV) CELLS ON ENDURING DoD INSTALLATIONS IN THE MIDDLE EAST: A FEASIBILITY STUDY

Ijaz Ahmad–Commander, Pakistan Navy
Patrick Shouvlin–Lieutenant, United States Navy
Master of Business Administration
Lead Advisor: John Khawam, Graduate School of Business and Public Policy
Support Advisor: Keebom Kang, Graduate School of Business and Public Policy

The focus of this research is to ascertain the feasibility of the use of solar energy on enduring Department of Defense (DoD) installations located throughout the Middle East. DoD installations are currently using electricity generated either from the local grids at commercial rates, or contractor -provided diesel generators. Growing commercial use of solar energy demands proper analysis for its viability on use at DoD facilities.This paper will analyze available solar tech nology, its cost effectiveness in the military environment, power requirements of DoD installations, and economies of scale based on power consumption. We will provide a brief summary of the latest research in the field of solar energy, including current status, future prospects and issues related with the use of solar energy, and ways to resolve these issues especially with regard to availability, cost, and sustainability. A look at future plans for the use of renewable alternate energy sources within the DoD shall give us some guidelines with respect to their effect on power requirements vis-à-vis future cost structure. Based on the results of the research some statistical analysis may be carried out. The outcome of our analysis shall be translated into recommendations for DoD leadership for future planning and acquisition activities. http://calhoun.nps.edu/handle/10945/34617

KEYWORDS: PV cells, solar irradiance, Photo voltaic effect, Life cycle cost, Total ownership cost, Levelized cost of electricity

THE ORIGIN OF THE DEPARTMENT OF THE NAVY'S BIOFUEL INITIATIVE AND THE VOLATILITY PROBLEM FOR DEFENSE ENERGY

Gary A. Blumberg–Lieutenant Commander, United States Navy Reserve
Master of Business Administration
Advisor: David R. Henderson, Graduate School of Business and Public Policy
Co-Advisor: Brad Naegle, Graduate School of Business and Public Policy

This thesis presents three catalysts for the origins of the Department of the Navy's biofuel initiative: (1) Section 526 of the Energy Independence and Security Act of 2007 effectively ended the Department of Defense's (DoD's) research program into synthetic fuels derived from fossil fuels; (2) the crude oil spot price reached a maximum daily price of $145.16 on July 14, 2008; and (3) the American Recovery and Reinvestment Act of 2009 appropriated over one billion dollars for biomass research and development. Although cost volatility has impacted the DoD's budget, the DoD already has used the Defense Working Capital Fund to make perceived oil prices less volatile to DoD users. Drop-in replaceable biofuels would not remove petroleum price volatility because biofuels act as close substitutes. The governments of other countries reduce cost volatility by managing fuel price risk using futures contracts; opinions differ on whether the DoD should pursue this option. To mitigate cost volatility, the Defense Business Board recommended exploring intragovernmental

transfers between the DoD and Department of the Interior on two occasions. Long-term contracts could reduce volatility, but the DoD risks losing competitors in supply. http://calhoun.nps.edu/handle/10945/34632

KEYWORDS: Biofuel, Drop-in Replaceable, Volatility, Defense Production Act, Energy Independence and Security Act, American Recovery and Reinvestment Act, Defense Working Capital Fund, Intragovernmental Transfers, Long-term Contracts, Close Substitutes

ORGANIZATIONAL ANALYSIS OF ENERGY MANPOWER REQUIREMENTS IN THE UNITED STATES NAVY

Nicholas A. Devorak
Lieutenant Junior Grade–United States Navy
Master of Business Administration
Advisor: Bill Hatch, Graduate School of Business and Public Policy
Co-Advisor: Cary Simon, Graduate School of Business and Public Policy

The Secretary of the Navy (SECNAV) directed NPS to establish energy-focused subspecialty codes (SSC) that will prepare officers to manage all aspects of energy. In response to this SECNAV directive NPS has developed four energy-focused degree plans in the areas of Operations Analysis, Financial Management, Mechanical and Electrical Engineering. An analysis of the current force structure requirements was necessary to assess and implement a new direction. At the present time, the Navy utilizes petroleum management officers as energy managers. Unfortunately, the Navy Officer Billet Classification (NOBC) Codes assigned to these officers do not translate into the identification of the billets being identified with the energy SSCs. Analysis shows a possible solution to this issue is to establish afloat and ashore general Energy NOBCs that could be assigned as either a primary or secondary NOBC Energy billets. Specifically, analysis shows the majority of NOBCs assigned to energy billets are from the Naval Operations (90009999) Field. Therefore, this research recommends the establishment of two Energy NOBCs to support future Fleet Energy Management Challenges. http://calhoun.nps.edu/handle/10945/34655

KEYWORDS: Energy, Conservation, SECNAV, Requirements, Manpower, Force Structure, Navy Officer Occupational Classification, NOBC, Educational Skills Requirements, ESR, Subspecialty Code, SSP

MORE FIGHT–LESS FUEL: REDUCING FUEL BURN THROUGH GROUND PROCESS IMPROVEMENT

Chad A. Gerber, Lieutenant Commander, United States Navy
Jeremy A. Clark, Lieutenant Commander, United States Navy
Master of Business Administration
Lead Advisor: Michael Dixon, Graduate School of Business and Public Policy
Support Advisor: Uday Apte, Graduate School of Business and Public Policy
Support Advisor: Roberto Szechtman, Department of Operations Research

Aligning fiscal policies with energy conservation initiatives and operational requirements is vital to achieving a positive and sustainable energy outlook for the United States Navy. The purpose of this study is to fill critical gaps in current military aviation energy conservation research. To date, such research has failed to incentivize and reward individual aviation squadrons to conserve. Commercial aviation uses collaborative decision-making (CDM) tools to minimize costs associated with aircraft delays. Embracing a lean approach to operational management, the commercial sector has refined communications between air carriers, airport operators, ground handlers, and air traffic control. This

study suggests applying commercial CDM frameworks to all of Naval Aviation to increase efficiency and operational effectiveness. Specific analysis includes the impact of ground resource capacity management, airfield demand analysis (slot arrival system) and demand management cost analysis on F/A-18 Hornet squadrons. http://calhoun.nps.edu/handle/10945/34667

KEYWORDS: Energy conservation, slot management, demand analysis, truck refueling, hot skid refueling, Simio, modeling and simulation, discrete event simulation, F/A-18, cultural change

BIOFUEL: A COMPARATIVE CASE STUDY

Aamir Siddiqui–Wing Commander, Pakistan Air Force
Christopher Kading–Lieutenant, United States Navy
Kasey Carter–Lieutenant, United States Navy
Master of Business Administration
Advisor: Jason Hansen, Graduate School of Business and Public Policy
Co-Advisor: Kathryn Aten, Graduate School of Business and Public Policy

This project analyzes the government's role in the commercialization of biofuel by comparing biofuel commercialization efforts to those of nuclear power and nanotechnology commercialization. The PESTEL framework is applied to nuclear power and nanotechnology to identify key factors relevant to successful commercialization. These success factors are compared to current government biofuel policies to infer the likelihood of successful biofuel commercialization. In closing we recommend changes to government policy to improve the prospect of biofuel commercialization. http://calhoun.nps.edu/handle/10945/34746

KEYWORDS: Biofuel, commercialization, case study, nuclear power, nanotechnology, government, policy, initiatives, alternative energy, algae

Electrical and Computer Engineering

OPTIMIZING GAS GENERATOR EFFICIENCY IN A FORWARD OPERATING BASE USING AN ENERGY MANAGEMENT SYSTEM

Ryan L. Kelly
Captain–United States Marine Corps
Master of Science in Electrical Engineering
Co-Advisor: Giovanna Oriti, Department of Electrical and Computer Engineering
Co-Advisor: Alexander L. Julian, Department of Electrical and Computer Engineering

A Forward Operating Base (FOB) is designed to support combat operations in an austere environment, which often lacks pre-existing infrastructure. On-site diesel generators are the primary source of FOB electricity. Traditionally, each generator is connected to its own set of loads and operates independently from other generators. The benefits of transitioning from traditional generator employment to an alternative architecture using an Energy Management System (EMS) were investigated in this thesis. The EMS provides an interface between power sources, loads, and energy storage elements to form a microgrid. Using power electronics and programmable logic, the EMS provides capabilities such as power source selection, power metering, flow control, and peak power management. These capabilities enable more efficient generator utilization by matching real time load demand to the smallest capable power source, reducing overall fuel consumption. The EMS offers redundancy as it can connect any one of multiple power sources to critical loads. A

hardware-based laboratory experiment demonstrated the ability to transition from one power source to another while providing uninterrupted current to the load. The results of the experiment validate a Simulink model of the EMS. An example load profile was applied to the model to compare overall fuel consumption between the traditional architecture and EMS-enabled microgrid. http://calhoun.nps.edu/handle/10945/34686

KEYWORDS: Energy management system, forward operating base (FOB), generators, Microgrid, power electronics

H-BRIDGE INVERTER LOADING ANALYSIS FOR AN ENERGY MANAGEMENT SYSTEM

Andrew James Metzcus
Lieutenant–United States Navy
Master of Science in Electrical Engineering
Advisor: Giovanna Oriti, Department of Electrical and Computer Engineering
Co-Advisor: Alexander L. Julian, Department of Electrical and Computer Engineering

The Department of the Navy (DON) is committed to reduce its reliance on fossil fuels. Secretary of the Navy Ray Mabus has said, The underlying reasons for reform are clear. Our energy sources are not secure, we need to be more efficient in energy use, and we emit too much carbon. Microgrids utilizing an Energy Management System (EMS) may be the answer to control and route power more efficiently. The power quality achieved from a single phase pulse-width modulation (PWM) voltage source inverter (VSI) (the heart of an EMS) driving an inductive and capacitive (LC) filter with linear and non-linear loads was investigated in this thesis. The open loop PWM waveforms are compared to the power quality standards for ship board power, MIL-STD-1399-300B. This quantifies the performance limits of open loop PWM, which is the simplest control strategy for a single-phase VSI. Closed loop control is shown to be necessary when larger loads are connected to the VSI in order to prevent output voltage sag. http://calhoun.nps.edu/handle/10945/34706

KEYWORDS: Energy Management System, microgrid

SIMULATING AND TESTING A DC-DC HALF-BRIDGE SLR CONVERTER

Mark E. Pfender
Ensign–United States Navy
Master of Science in Electrical Engineering
Advisor: Alexander L. Julian, Department of Electrical and Computer Engineering
Second Reader: Giovanna Oriti, Department of Electrical and Computer Engineering

In order to obtain maximum battery lifetime and efficient operation, rechargeable batteries require unique charging profiles with an end-state, low current trickle charge. The series loaded resonant (SLR) charging system presented in this thesis meets the needs of an efficient, sensor integrated, and galvanically isolated trickle charger. The SLR DC-DC converter was successfully modeled in Simulink, and simulation results are verified in a laboratory application. The Simulink model and hardware are tested at several operating points. Component stresses are quantified and weak points are identified. http://calhoun.nps.edu/handle/10945/34721

KEYWORDS: series loaded resonant (SLR), battery charging, DC-DC, pulse power, power electronics, SLR converter

RADAR CROSS SECTION (RCS) SIMULATION FOR WIND TURBINES

Cuong Ton
Master of Science in Electrical Engineering
Advisor: David C. Jenn, Department of Electrical and Computer Engineering
Second Reader: Ric Romero, Department of Electrical and Computer Engineering

Wind-turbine power provides energy-independence and greenhouse-gas reduction benefits, but if wind turbines are built near military and commercial radar and communication installations, they can cause degradation in the systems performance. The purpose of this research is to study the radar cross section (RCS) of a wind turbine and assess its effect on the performance of radar and communication systems. In this research, some basic scattering characteristics of wind turbines are discussed. Several computational methods of RCS prediction are examined, citing their advantages and disadvantages. Modeling and computational issues that affect the accuracy and convergence of the simulation results are discussed. RCS simulation results for two wind turbine configurations are presented: a horizontal axis, three-blade design and a vertical axis helical design. Several methods of mitigating wind turbine clutter are discussed. Issues of RCS reduction and control for wind turbines are also addressed. http://calhoun.nps.edu/handle/10945/34754

KEYWORDS: Radar Cross Section, wind turbine, simulation, model, surface meshing, RCS reduction, Lucernhammer, bistatic, monstatic, three-blade, helical, clutter, Doppler, numerical method

Mechanical and Aerospace Engineering

DESIGN AND QUALIFICATION OF A HIGH-PRESSURE COMBUSTION CHAMBER FOR IGNITION DELAY TESTING OF DIESEL FUELS

Warren P. Fischer
Ensign–United States Navy
Master of Science in Mechanical Engineering
Co-Advisor: Christopher M. Brophy, Department of Mechanical and Aerospace Engineering
Co-Advisor: Patrick A. Caton, Department of Mechanical and Aerospace Engineering

A high pressure and temperature combustion chamber was designed to compare the ignition properties of different fuels, including conventional F76 diesel and hydrotreated renewable diesel (HRD), derived from algae. Conditions were selected to capture the operating conditions within a large number of Navy systems, testing at a range of temperatures from 8001340 F and pressures as high as 20 atm. Three Navy-relevant injectors were procured for the testing as well as a commercial injector made by Sturman Industries. The Sturman diesel injector was characterized up to a fuel tip pressure of 9600 psi and produced Sauter Mean Diameters of approximately 90 microns, generally showing improved atomization for F-76 when compared to HRD at similar conditions. The combustion chamber utilized dynamic air injection with increased turbulence and the ability to alter the amounts of combustion products including CO, CO2 and H2O that typically exist in real engines from the previous combustion event. Qualification testing of the combustion chamber evaluated final pressures of up to 15 atmospheres and temperatures of 472 F, but revealed heat losses during the dynamic air injection events, resulting in temperatures below expected values and auto-ignition conditions for fuels under consideration. A fluidized bed heat exchanger will be implemented to supplement the existing design and reach the desired temperatures. http://calhoun.nps.edu/handle/10945/34662

KEYWORDS: F-76; HRD; High-pressure; Ignition delay; Diesel injectors; Alternative fuels

MOLYBDENUM CARBIDE SYNTHESIS USING PLASMAS FOR FUEL CELLS

John J. Lugge
Lieutenant–United States Navy
Master of Science in Mechanical Engineering
Advisor: Jonathan Phillips, Department of Physics
Co-Advisor: Claudia Luhrs, Department of Mechanical and Aerospace Engineering

Currently, carbon is the preferred support material for platinum catalyst particles used in polymer electrolyte fuel cells (PEFCs). Carbon possesses qualities needed for a fuel cell catalyst: high surface area and conductivity, but is unacceptable as it is prone to oxidization by carbon dioxide in the fuel cell environment. Molybdenum Carbides is known to have the required conductivity. However, making Mo2C with sufficient surface area and with stabilized platinum remains a materials challenge. In this work a novel approach, a variation on the Aerosol-Through-Plasma (ATP) method was employed for making Mo2C with high surface area and stable supported platinum particles. An ammonium molybdate precursor was processed through different ATP conditions to generate the catalyst. These particles were then characterized using X-ray diffraction and SEM techniques in order to produce a support material with the highest concentration of Mo2C. Using the ideal conditions for the ATP, precursor was loaded with platinum and then processed through the ATP. This sample was then characterized using X-ray and SEM techniques to insure that the material was suitable prior to testing the electrochemical properties under PEFC operating conditions. The results were then compared to other leading support catalysis. http://calhoun.nps.edu/handle/10945/34700

KEYWORDS: Molybdenum carbines, fuel cells, aerosol-through-plasma, catalysts

INITIAL INVESTIGATION OF A NOVEL THERMAL STORAGE CONCEPT AS PART OF A RENEWABLE ENERGY SYSTEM

Lindsay M. Olsen
Ensign–United States Navy
Master of Science in Mechanical Engineering
Advisor: Anthony J. Gannon, Department of Mechanical and Aerospace Engineering
Co-Advisor: Garth V. Hobson, Department of Mechanical and Aerospace Engineering

This thesis forms part of a larger study that aims to develop a renewable energy demonstration plant at the Naval Postgraduate School Turbopropulsion Laboratory. The architecture and design approach of the demonstration plant is outlined in this thesis. While all the components of the system are commercially available, the integration of the components is challenging. The results of the design approach presented the optimal way of integrating wind turbines, an electrical system, chiller units, and thermal storage tanks. Modular ice thermal tanks with polypropylene tubing were chosen for storage. The ice thermal storage units were selected over battery storage as they are more cost effective and potentially safer. A statistical analysis was performed using wind data from Monterey Airport, which was beneficial for choosing which wind turbines to implement in the system. The analysis determined that total energy captured by two, 4-kW vertical axis wind turbines was 2,554.8 kW-hours annually. Additionally, ANSYS Fluent was used to analyze the ice growth around the tubing at various ice and tube thicknesses. The ANSYS Fluent analysis showed that ice thickness affects the ice volume growth and change in enthalpy change more than wall thickness affects these conditions. http://calhoun.nps.edu/handle/10945/34716

KEYWORDS: Renewable energy, thermal ice storage, chiller, cooling, wind energy

COMBUSTION HEAT RELEASE RATE COMPARISON OF ALGAE HYDROPROCESSED RENEWABLE DIESEL TO F-76 IN A TWO-STROKE DIESEL ENGINE

John H. Petersen
Lieutenant–NOAA Commissioned Officer Corps
Master of Science in Mechanical Engineering
Advisor: Knox T. Millsaps, Department of Mechanical and Aerospace Engineering
Co-Advisor: Douglas L. Seivwright, Department of Mechanical and Aerospace Engineering
Second Reader: Patrick A. Caton , Department of Mechanical and Aerospace Engineering

This thesis compared the combustion performance of algae-based hydroprocessed renewable Diesel fuel (HRD) and HRD/F-76 blends, to that of conventional Naval Diesel fuel, F-76. The tests were conducted using a two-stroke, direct injected Detroit 3-53 Diesel engine. The cetane number (CN) of the HRD used was 78 while the CN of the F-76 used was 46. The start of injection (SOI) was measured with a strain gauge mounted on the mechanical fuel injector rocker arm. SOI was found to advance as load increased and retard as speed increased; however, SOI remained constant with the use of the different fuels HRD or F-76. Ignition delay (IGD) decreased significantly with HRD which is consistent with the much higher CN. The heat release rate analysis performed determined that the shorter IGD of HRD led to later combustion phasing, increased overall combustion duration and lower maximum rate of pressure rise. The use of HRD also resulted in lower max cylinder pressure. These results suggest that the combustion performance of HRD has no detrimental effects on the Diesel engine tested. http://calhoun.nps.edu/handle/10945/34720

KEYWORDS: Hydroprocessed Renewable Diesel, HRD, Algae Derived Alternative Fuels, Bio-derived Fuels, Renewable Diesel, Alternative Fuel Blends, HVO, F-76, Heat Release Rate, Energy Release Rate, Diesel Engine Combustion

METHOD FOR VAWT PLACEMENT ON A COMPLEX BUILDING STRUCTURE

Katharin C. Taylor
Ensign–United States Navy
Master of Science in Mechanical Engineering
Advisor: Anthony J. Gannon, Department of Mechanical and Aerospace Engineering
Co-Advisor: Garth V. Hobson, Department of Mechanical and Aerospace Engineering

This thesis is part of a larger project that will demonstrate the feasibility of powering a commercially sized 7.5-ton cooling system. Excess cooling will be stored thermally using ice. This system has the potential to be used in military bases to reduce energy costs and fossil fuel consumption. A scaled down version would be suitable for data centers and forward operating bases where the transport of fuel can be costly and dangerous. The system will be built and operated at the Turbopropulsion Laboratory (TPL) of Naval Postgraduate School. This thesis concentrates on the choice and location of wind turbines used to power the cooling system. A simulation of Building 216, which is the planned site of the cooling system, was performed. A wind flow analysis found that optimum placement of the wind turbines is at the front of the south end of the building. The method for placing the wind turbines is outlined and applicable to other structures. Vertical Axis Wind Turbines (VAWTS) were found to be the most suitable for site location. A transient analysis of the VAWTS was necessary to accurately simulate their performance. This supported the selection of a three-bladed helical VAWT design. Further simulations of wind turbine separation showed some beneficial effects of close spacing. http://calhoun.nps.edu/handle/10945/34752

KEYWORDS: Commercial cooling system, vertical axis wind turbines, horizontal axis wind turbines, computational fluid dynamics (CFD)

Physics

MEMS-BASED WASTE VIBRATIONAL ENERGY HARVESTERS

Daniel B. Hogue
Lieutenant–United States Navy
Master of Science in Physics
Advisor: Dragoslav Grbovic, Department of Physics
Second Reader: Gamani Karunasiri, Department of Physics

The piezoelectric effect is a phenomenon where strain on a piezoelectric crystal structure causes potential difference at its ends. By merging piezoelectric materials and microelectromechanical systems (MEMS), mechanical vibration could cause the necessary displacement in MEMS to create a potential difference that could be used to power electronic devices. Developing new sustainable energy sources and using energy more efficiently is at the forefront of several research initiatives and is a clear priority for the Department of the Navys strategic planning. This thesis aims to design a vibrational energy harvesting MEMS device to harness vibrational waste energy with the goal of producing power for naval applications. The development and widespread use of vibrational harvesting MEMS would aid the effort to meet each of these goals in the Department of the Navy. Any shore based, seagoing, or expeditionary mechanical platform could serve as a kinetic energy source for vibration energy harvesting MEMS. This thesis investigates the physics, materials, design, optimization, and microfabrication process in the creation of such a device. Time-dependent finite element models for two designs have been developed, simulating electrical power output. Microfabrication processes for the designs have also been developed. http://calhoun.nps.edu/handle/10945/34678

KEYWORDS: Energy harvesting, MEMS, piezoelectric

ISOTOPE MIXES, CORRESPONDING NUCLEAR PROPERTIES AND REACTOR DESIGN IMPLICATIONS OF NATURALLY OCCURRING LEAD SOURCES

Daniel J. Watts
Ensign–United States Navy
Master of Science in Applied Physics
Advisor: Craig Smith, Department of Physics
Second Reader: Gamani Karunasiri, Department of Physics

Lead-cooled Fast Reactors (LFRs) offer great potential for future compact nuclear power systems. The Small, Secure, Transportable, Autonomous Reactor (SSTAR) is a concept for an advanced fast reactor cooled by lead. Such reactors could be improved by using lead that is enriched in radiogenic lead (e.g., 208Pb) in contrast to the average natural isotopic concentration. This improvement is due to the improved neutron reflection and lower neutron absorption cross-sections of the radiogenic isotopes. Artificial isotope separation of lead is cost-prohibitive; however, a natural lead source that is high in 208Pb and low in 204Pb could be used to improve the design of the reactor. The natural variation of lead isotopic content is geochemically investigated to determine if there are favorable naturally occurring lead sources. The results of the investigation are then used in Monte-Carlo

simulations with the MCNP5 code to determine the potential benefits of using such a lead composition to the design of a simplified SSTAR-type reactor. The results demonstrate that natural lead sources high in 208Pb could lead to a reduction in the required core enrichment of up to 1 percent; this benefit could also be applied to make the design smaller, or to increase the power output. http://calhoun.nps.edu/handle/10945/34758

KEYWORDS: nuclear physics, nuclear engineering, nuclear reactor, SSTAR, MCNP, MCNP5, monte carlo transport, geochemistry, lead, uranium, thorium

Systems Engineering

EXPLORING THE FEASIBILITY OF PROVIDING ELECTRICAL POWER TO REMOTE BASES VIA SPACE-BASED SOLAR POWER SATELLITES

David J. Chow–Civilian, United States Air Force
Master of Science in Systems Engineering Management
Advisor: Mark M. Rhoades, Department of Systems Engineering
Second Reader: Eugene P. Paulo, Department of Systems Engineering

Delivering electrical power to remote military bases can be an expensive and dangerous task. The idea of delivering renewable power to remote military bases through space-based solar power has existed for many years, but has not yet materialized. This research sought to examine existing studies and leverage their findings to determine a systems architecture and subsequent design alternatives that could deliver space-based solar power to a military base in Afghanistan. Three design alternatives were created and were based on the defined systems architecture. The system attributes vary by design alternative, to include transmitter size, rectenna size, power transmitted, mass of components, and number of launches required. The design attributes were weighted accordingly to stakeholder objectives. In turn, the entire design alternative was given a Measure of Effectiveness score. This score was used to determine the most effective design alternative among the designs presented in this research. The result is one of the three designs conclusively meets stakeholder requirements and is more effective than the others, yet further research should be done to improve the design and address other concerns, such as the extremely high cost of the system and the potential environmental and safety issues of the high-power microwave beam. http://calhoun.nps.edu/handle/10945/34645

KEYWORDS: Space-Based Solar Power, Power Beaming, Wireless Power Transmission

FEASIBILITY STUDY AND SYSTEM ARCHITECTURE OF RADIOISOTOPE THERMOELECTRIC GENERATION POWER SYSTEMS FOR USMC FORWARD OPERATING BASES

Ryan C. Langham–Lieutenant, United States Navy
Master of Science in Systems Engineering
Advisor: Fernand Marquis, Department of Systems Engineering
Second Reader: Eugene P. Paulo, Department of Systems Engineering

This study sought to identify the feasibility of utilizing a radioisotope thermal (thermoelectric/ stirling) generator to provide power to a deployed USMC Expeditionary Force. The conceptual system architecture was constructed through use of the systems engineering process, identifying necessary subsystems and integration boundaries. Radioisotope comparison was then performed,

utilizing weighted design factors. It was determined that Sr-90, Cs-137, and Cm-244 would be the most effective fuel sources for this mission area. By analyzing current thermoelectric technology, it was determined that maximum system efficiency is limited to 1015 percent when utilizing available lead telluride thermoelectrics. Barriers to development of identified physical subsystem components were then identified, including health and environmental hazards of potential isotopes, as well as shielding criteria. The system development was found to be feasible and additional design work and development work is proposed. http://calhoun.nps.edu/handle/10945/34695

KEYWORDS: Energy, USMC, E2O, radioisotope, generator, alternative energy

VIABLE SHORT-TERM DIRECTED ENERGY WEAPON NAVAL SOLUTIONS: A SYSTEMS ANALYSIS OF CURRENT PROTOTYPES

Cohort 19/Team Bravo
Master of Science in Systems Engineering Analysis
Advisor: Gary O. Langford, Department of Systems Engineering
Second Reader: Thomas Anderson, Department of Systems Engineering

With conventional weapons nearing their peak capability, the need to identify alternative war fighting solutions suggests a look at Directed Energy Weapons (DEWs). The goal is to change the means by which warfare is conducted to improve operational efficiencies and overall effectiveness. The Naval Postgraduate School Systems Engineering and Analysis (SEA-19B) Capstone project team examined how existing directed energy technologies can provide performance across multiple warfare area domains and mission subsets for the U.S. Navy. The aim was to identify and characterize the capability gaps with conventional weapons systems, produce a coherent vision of naval missions that incorporate DEWs, and generate a roadmap for a DEW fleet. By conducting a thorough Analysis of Alternatives based on system performance, integration, schedule, and cost, the project team identified that the Tactical Laser System (with a laser beam power of 10 kW) provided the best overall capability to defend surface combatants, although none of the analyzed DEWs have the capability to replace a current conventional weapon. The Active Denial System (microwave) provided a niche capability in the Anti-Terrorism/Force Protection mission set. http://calhoun.nps.edu/handle/10945/34734

Keywords: Directed Energy, DE, Directed Energy Weapon, DEW, Global Information Network Architecture, GINA, High-Powered Microwave, HPM, LASER, Meta-Model

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Computer Science

ENERGY EFFICIENT GROUP CONTEXT AWARE SENSOR MANAGEMENT STRATEGY FOR TACTICAL OPERATIONS

Samantha A. Graves–Captain, United States Marine Corps
Master of Science in Computer Science
Advisor: Gurminder Singh, Department of Computer Science
Co-Advisor: John H. Gibson, Department of Computer Science

Shared situational awareness (SSA) is essential to success and safety in tactical environments, whether fighting wars or providing relief during disasters and humanitarian catastrophes. The increased availability of sensors in mobile devices offers groundbreaking opportunities for continuous context-aware applications that are capable of responding to the operating conditions of users and their environment. However, continuous context-aware applications involve high-energy consumption. A key challenge in tactical environments is to make the most effective use of scarce resources. There are numerous approaches for reducing energy consumption of continuous context-aware applications. This thesis examines two methods: Sensor Substitution and Triggering (SENST) and Acquisitional Context Engine (ACE). The goal of this thesis is to explore the capabilities and limitations of SENST and ACE for group context-awareness and provide a group energy-efficient sensor management strategy that enhances the dissemination of SSA in tactical environments.
http://calhoun.nps.edu/handle/10945/37633

KEYWORDS: Group Context Aware Applications, Sensor Management, Continuous Context Sensing, Energy Efficiency

Electrical and Computer Engineering

ULTRA LOW-VOLTAGE ENERGY HARVESTING

Alan P. Cabiling–Lieutenant, United States Navy
Master of Science in Electrical Engineering
Advisor: Alexander L. Julian, Department of Electrical and Computer Engineering
Second Reader: Roberto Cristi, Department of Electrical and Computer Engineering

The U.S. Navy has many opportunities to take advantage of energy sources that are usually wasted because these low power sources yield such low-voltages that a normal voltage converter is not efficient enough to harvest the energy. Low-voltage energy is available in many forms including solar, thermal, vibration, and electro-magnetic. The power that can be obtained from these sources on a small scale can be taken advantage of by using an ultra-low power boost converter that is specifically designed for energy harvesting applications. These energy sources with a very small footprint can be used in military and defense applications such as wireless sensor networks, industrial monitoring, and varieties of portable and wearable devices. The theory of power conversion, synchronous rectification, and maximum power point tracking is discussed. A discussion of the benefits of using an energy converter made specifically for energy harvesting is also covered. A commercially available energy harvester converter is simulated using a simulation program with integrated circuit emphasis,

and a solar application is tested with hardware. The hardware experiments explore the startup sequence of the circuit, the switching profile of the converter, and a test of the circuits efficiency. http://calhoun.nps.edu/handle/10945/37593

KEYWORDS: Energy harvesting, power conversion, boost converter, maximum power point tracking, synchronous converter, renewable energy

AN INVESTIGATION OF THE EFFECTIVENESS OF SOLAR POWER ON NAVY SURFACE COMBATANTS

Justin P. Kirkpatrick
Lieutenant–United States Navy
Master of Science in Electrical Engineering
Advisor: Sherif Michael, Department of Electrical and Computer Engineering
Second Reader: Daniel Nussbaum, Department of Operations Research

With energy consumption and environmental concerns taking the forefront in this nation, the United States Navy is playing its part by committing itself to reduce its reliance on fossil fuels both at sea and ashore. Solar power is one method by which the Navy can help reach its energy goals. The practicality of equipping its surface combatants with solar panels to aid in the generation of shipboard power in order to reduce the consumption of traditional fossil fuels is examined in this thesis. Such a measure would be beneficial both at sea and in port, for the sun does not discriminate where it shines. In order to accomplish this, research was done into the available surface area associated with various ship classes, current fuel and energy consumption figures both at sea and in port, estimates of how much fuel and money could be saved, what effect the panels will have on tactical factors, and different means of storing the energy generated from the panels. http://calhoun.nps.edu/handle/10945/37652

KEYWORDS: Solar power, navy surface combatants, energy storage, tactical feasibility

Operations Research

LIFE-CYCLE COST MODELING TO DETERMINE WHETHER VEHICLE-TO-GRID (V2G) INTEGRATION AND ANCILLARY SERVICE REVENUE CAN GENERATE A VIABLE CASE FOR PLUG-IN ELECTRIC DRIVE VEHICLES

Joseph F. Monahan–Captain, United States Marine Corps
Master of Science in Operations Research
Advisor: Daniel Nussbaum, Department of Operations Research
Second Reader: Alejandro Hernandez, Department of Systems Engineering

In an effort to increase U.S. energy security by reducing oil consumption, various federal mandates and executive orders require reduced petroleum use and greenhouse gas emissions by federal non-tactical vehicle fleets. Transitioning federal fleets to plug-in electric drive vehicles (PEDVs) is one option to meet these mandates. This research performs a life-cycle cost analysis using modeling and simulation to determine the parameters under which vehicle-to-grid (V2G) integration and associated revenue streams can create a viable economic case for the transition of federal fleets to PEDVs. Under current market conditions, bidirectional V2G frequency regulation (FR) is not currently viable. Unidirectional FR has potential, but it provides minimal reductions in PEDV life-cycle cost. The cost

to meet petroleum reduction mandates by transitioning light-duty fleets to PEDVs is cost prohibitive and impractical, requiring almost a complete one-for-one replacement of the current fleet of traditional light-duty passenger vehicles. Realistically meeting the mandate without fleet downsizing will require implementing a transition toward alternatively fueled vehicles beyond the light-duty passenger vehicle class. However, economic justification will require a reduction in PEDV acquisition costs or improved market conditions for V2G FR (consisting of lower throughput and higher regulation market clearing prices) thereby resulting in considerably greater net revenue. http://calhoun.nps.edu/handle/10945/37678

KEYWORDS: Life Cycle Cost Analysis, Vehicle to grid (V2G), Energy Modeling, Ancillary Services, Frequency Regulation, Plug-in Electric Drive Vehicles, Hybrid Electric Vehicles, Alternatively Fueled Vehicles (AFV), Federal Petroleum Reduction Mandates, Energy Independence, Electrical Grid, Alternative Energy Solutions

Security Studies

POLICY IN CONFLICT: THE STRUGGLE BETWEEN ENVIRONMENTAL POLICY AND HOMELAND SECURITY GOALS

Daniel R. Cowden–Regional Security Officer, U.S. Department of the Interior
Master of Arts in Security Studies (Homeland Security and Defense)
Advisor: Thomas Mackin, Center for Homeland Defense and Security
Co-Advisor: Lauren Fernandez, Center for Homeland Defense and Security

Since the 1970s, every American president and many Congressional leaders have called for national energy independence as a top policy priority. Among many reasons the United States (U.S.) has been unable to deliver on this goal over four decades are certain environmental policies that may tend to inhibit efficiency in fuel consumption of vehicles. This study examines the unintended consequences of certain environmental policies for American homeland security. The analyses suggest that some environmental policies may have a deleterious effect on the ability of the United States to achieve a level of energy efficiency in the transportation sector that could contribute to achieving national energy security. This study suggests ways to achieve a level of sustainable energy security by reducing consumption in the most important petroleum consuming sector, that of automobile transportation. Some U.S. oil dollars may be directly supporting terrorist organizations or, at a minimum, go toward supporting the spread of radical Islamic Salafism that is inimical to U.S. and Western interests. This inquiry examines evidence to show that Americas continuing dependence on other foreign oil, especially oil from the Middle East, is perilous to homeland security and compels limits to U.S. freedom of action in foreign affairs. http://calhoun.nps.edu/handle/10945/37605

KEYWORDS: Policy Conflicts, Environmental Policy vs. Homeland Security Goals, Energy Security, Petrodollars Supporting Islamic Radicalization and Terrorism

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Graduate School of Business and Public Policy

ANALYSIS OF MARINE CORPS RENEWABLE ENERGY PLANNING TO MEET INSTALLATION ENERGY SECURITY REQUIREMENTS

Christopher M. Chisom–Captain, United States Marine Corps
Jack C. Templeton II–Captain, United States Marine Corps
Master of Science in Management
Advisor: Nicholas Dew, Graduate School of Business and Public Policy
Co-Advisor: Geraldo Ferrer, Graduate School of Business and Public Policy

The purpose of this thesis is to analyze Marine Corps installation energy consumption and the pursuit of increased renewable energy generation goals across Marine Corps installations. The main objective of this report is to determine the cost of interruption and the net present value (NPV) of renewable energy generation needed to meet the Marine Corps energy security objectives. First, we determine installation-specific energy consumption, resource requirements, and current renewable energy generation projects. Second, we analyze current Marine Corps installation energy portfolios to determine shortfalls from minimum energy targets and the cost to generate those shortfalls through renewable energy technologies. Finally, we identify installation energy security requirements, determine cost of interruption, and conduct a sensitivity analysis of the cost-benefit of renewable energy generation alternatives to meet energy security requirements. This study determines how investment in renewable energy to meet baseline energy consumption requirements increases energy security across Marine Corps installations. Furthermore, considering the cost of interruption, the investment in renewable energy technologies yields a positive NPV at the majority of Marine Corps installations. Based on this research, we recommend that the Marine Corps develops a quantitative method for assessing energy security and invest to meet energy security goals at each installation.
http://calhoun.nps.edu/handle/10945/38899

KEYWORDS: Renewable Energy, Energy Security, Marine Corps Installations, Learning Curve Analysis, Modern Portfolio Theory, Solar, Wind, Biomass, Waste-to-energy, Energy Planning, Energy Strategy, Customer Damage Function, Cost of Interruption, Probability of Interruption

KEY DRIVERS OF MARINES' WILLINGNESS TO ADOPT ENERGY-EFFICIENT TECHNOLOGIES

Jason C. Ciarcia–Captain, United States Marine Corps
Master of Business Administration
Advisor: Kathryn Aten, Graduate School of Business and Public Policy
Co-Advisor: Douglas Brinkley, Graduate School of Business and Public Policy

Why individuals adopt or resist technologies is a central question in technology management and energy conservation research. Much academic attention focuses on functional and economic advantages, but perceptions, habits, and norms play a more substantial role and are a particularly strong driver of resistance. Recognizing this, the Marine Corps Expeditionary Energy Office has called for research to better understand how messaging and behavioral factors will influence the shaping of a combat-effective energy posture within the Marine Corps. This research examines how particular individual attributes may affect Marines assessments of energy-efficient technologies. Drawing on a framework developed from the academic literature, this research focuses on the impact

of a persons prior conditions, knowledge, and perception of technologies on the decision to adopt, postpone, or resist new technologies. The research produced a summary of extant findings and implications for the United States Marine Corps concerning the typology of United States Marines perceptions and willingness to adopt energy-efficient technologies. The research findings may offer the Marine Corps a clearer understanding of acceptance and resistance drivers, and the means to facilitate greater acceptance of energy-efficient technologies. http://calhoun.nps.edu/handle/10945/38903

KEYWORDS: Marine Corps Expeditionary Office, energy-efficient technologies, technology resistance drivers and technology acceptance driver

USE OF ENERGY-EFFICIENT TECHNOLOGIES: U.S. MARINE CORPS' PERCEPTIONS TO ADOPTION

Vinh N. Nguyen–Major, United States Army
Daniel J. Eddy–Lieutenant, United States Navy
Jonathan B. Greenwald–Lieutenant, United States Navy
Master of Business Administration
Advisor: Kathryn Aten, Graduate School of Business and Public Policy
Co-Advisor: Becky Jones, Graduate School of Business and Public Policy

Identifying effective methods for influencing Marines to accept energy-efficient technologies is vital to achieving a positive and sustainable energy outlook for the United States Marine Corps (USMC). The purpose of this study is to support the adoption of energy-efficient technologies by the USMC to increase Marine combat effectiveness. Toward this end, Marines concerns, awareness, and enthusiasm regarding energy-efficient technologies were explored, as well as the influencers on these factors. This study and final recommendations are based on an analysis of focus group data from two focus groups held at the Naval Postgraduate School and two at Camp Pendleton. This analysis revealed key influence drivers and suggested potential influence strategies that the Marine Corps Expeditionary Energy Office can implement to help foster its initiatives. http://calhoun.nps.edu/handle/10945/38987

KEYWORDS: Marine Corps Expeditionary Office, Energy-Efficient Technologies, Influencers of Technology Adoption

ESTIMATING THE FULLY BURDENED COST OF SUPPLY IN A SELF-SUSTAINING SUPPLY CHAIN USING AN INPUT-OUTPUT MODEL

Hasan Temel–Major, Turkish Army
Baris Ayrus–Captain, Turkish Army
Mehmet Akif Aslan–Captain, Turkish Army
Master of Business Administration
Advisor: John Khawam, Graduate School of Business and Public Policy
Co-Advisor: Jay Simon, Graduate School of Business and Public Policy

Armed forces of many countries conduct various operations both at home and worldwide. These operations are conducted not only in areas where procurement is viable, but also in areas where commodities consumed by the logistics activities are not locally available. Estimating and calculating the fully burdened cost of supply in such areas where commodities consumed by the logistics activities are not locally available has become a major research and study field. This study focuses on the effects of change in vehicle fuel consumption rates on fully burdened cost of supplies in a self-sustaining supply chain and how the existence of demand at intermediate nodes affects the fully

burdened cost of supplies. After modeling five different scenarios, the effects of changes in the size of convoy and delivery system were analyzed by comparing the results of each scenario. The results of this analysis show that small convoys in supply chains are more efficient than big convoys, and the fuel consumption rate of vehicles is so crucial that it should not be disregarded when estimating fully burdened cost of fuel. http://calhoun.nps.edu/handle/10945/38876

Keywords: Fully Burdened Cost of Fuel (FBCF), Self-Sustaining Supply Chain (SSSC)

Electrical and Computer Engineering

POWER TRANSFER EFFICIENCY OF MUTUALLY COUPLED COILS IN AN ALUMINUM AUV HULL

James M. Cena–Lieutenant Commander, United States Navy
Master of Science in Electrical Engineering
Advisor: David Jenn, Department of Electrical and Computer Engineering
Second Reader: Alexander L. Julian, Department of Electrical and Computer Engineering

To charge the United States Navys Remote Environmental Measuring Units (REMUS) autonomous undersea vehicle (AUV) in situ requires the REMUS to mate with a docking station. There are two problems with this docking station. The docking system requires the REMUS to make electrical contact with the dock, which can lead to electrical shorting in an undersea environment. The dock is also designed to fit a single type of AUV. AUVs of different sizes require a new docking system. A different means of power transfer is required that can be used in a universal docking station. An inductive power transfer (IPT) system can be used in a universal docking station. In this report, we calculated the power transfer efficiency of an IPT system operating at 100 kHz using circular coils. These calculated results were then compared to three sets of measured efficiency data: an IPT system without ferrite tiles; an IPT system with the receiving coil attached to ferrite tiles; and an IPT system with the receiving coil/ferrite tile combination placed inside an aluminum AUV hull. Efficiency was poor, less than 10 percent with an air gap of 55 mm, when the receiving coil was placed inside the aluminum hull. http://calhoun.nps.edu/handle/10945/38895

KEYWORDS: Wireless power transfer, inductive power transfer, mutually coupled coils, autonomous undersea vehicle (AUV), power transfer efficiency, quality Factor (Q), coupling coefficient (k), two coil system

INTEGRATION AND CONTROL OF A BATTERY BALANCING SYSTEM

Peter L. Norgaard–Lieutenant, United States Navy
Master of Science in Electrical Engineering
Advisor: Alexander L. Julian, Department of Electrical and Computer Engineering
Second Reader: Giovanna Oriti, Department of Electrical and Computer Engineering

The primary focus of this research was the integration of series-loaded resonant (SLR) converters into a field-programmable gate array controlled power converter for use in balancing a series-connected battery bank. As the limits of the power grid are continually extended, the market demand for alternate power sources and energy storage systems will continue to grow. The goal of this research was to build and integrate a bank of SLR converters for use in balancing a series-connected battery bank that is part of a broader system used for power storage and conversion. Voltage and temperature sensors were used to monitor individual cell state-of-charge and rate-of-charge and

discharge. Voltage-to-frequency conversion was used to read sensor parameters. A battery balancing algorithm was designed, integrated and demonstrated with experimental results. http://calhoun.nps.edu/handle/10945/38989

KEYWORDS: power storage, series loaded resonant converter, voltage calibration, temperature sensing, battery balancing, field programmable gate array

Operations Research

OPTIMAL DAY-AHEAD SCHEDULING OF A HYBRID ELECTRIC GRID USING WEATHER FORECASTS

Hamadi Bouaicha–Lieutenant, Tunisian Navy
Master of Science in Operations Research
Advisor: Emily Craparo, Department of Operations Research
Co-Advisor: Dashi Singham, Department of Operations Research

The compromise between the stability of a hybrid electric grid (HEG) and the total operating cost can be reached by accurately anticipating the future renewable power productions. This thesis suggests the use of weather forecasts to establish day-ahead operating schedules for a grid that include the operating plan of dispatchable fuel-based generators, the charge or discharge of energy storage units, and the energy to exchange with the commercial grid if the configuration of the HEG allows it. The weather forecasts used as a key factor to establish the optimal plan are subject to uncertainty. In order to mitigate this problem, multiple weather forecast scenarios are used in the optimization. This thesis alters the optimization model to represent various configurations of the HEG and optimizes over a variety of weather forecasts. It then tests the operating plans suggested by the model using particular weather scenarios representing actual observed weather conditions. Finally, this thesis gives an illustration of how to run the optimization model with the rolling horizon method using updates of weather forecasts. http://calhoun.nps.edu/handle/10945/38882

KEYWORDS: Hybrid electric grid, Microgrid, Hybrid renewable energy system, energy management center, optimization, Day-ahead scheduling, Weather forecast, Wind power, Photovoltaic Power

Security Studies

DEVELOPING A RESILIENT GREEN CELLULAR NETWORK

Roger Sankerdial–Sergeant, New York City Police Department
Master of Arts in Security Studies (Homeland Security and Defense)
Advisor: Lauren Fernandez, Center for Homeland Defense and Security
Co-Advisor: Lauren Wollman, Center for Homeland Defense and Security

As technology drives society to a ubiquitously wireless world, the paradox of mobile wireless network accessibility versus resilience is disturbingly trending in opposite directions. The demand for cellular networks with greater capacity and bandwidth appears to be the primary factor in expanding coverage nationwide, with resilience becoming a secondary thought. It is expected that resilient systems will be able to withstand shocks and stresses from critical incidents and still be able to

function as intentionally designed. However, the fragility of cellular networks affected by recent disasters within the last ten years has demonstrated otherwise. The purpose of this research is to direct attention to the importance of cellular base station functionality during power outages and illustrate how these assets require modification to provide critical communications for the public to summon aid, and first responders to coordinate response efforts. Prior research offers strategies to implement post-disaster remediation supplanting failed localized communication infrastructure. This mitigating strategy requires substantial time, labor, and planning to deploy that subsequently detracts from conducting immediate response and recovery. This research is intended to propose a path forward for resiliency in U.S. mobile cellular networks using renewable/alternative energy outlined in Indias National Telecom Policy for 2012. http://calhoun.nps.edu/handle/10945/39006

KEYWORDS: Cellular Network Resilience, Green cell sites/base stations, renewable/alternative energy powered telecom networks, national public safety broadband network, India's cellular network

HIGH-TECH, LOW-TECH, NO-TECH: COMMUNICATIONS STRATEGIES DURING BLACKOUTS

Diana Sun Solymossy–Assistant County Manager and Director of Communications, Arlington, VA
Master of Arts in Security Studies (Homeland Security and Defense)
Advisor: Lauren Wollman, Center for Homeland Defense and Security
Co-Advisor: Richard Bergin, Department of Information Science

How do emergency managers communicate vital life-safety information when disaster strikes and the power goes out, sometimes for extended periods? Time and again, our power grid, aging and stretched beyond its intended capacity, has experienced failures. Power outages can quickly shift from being annoying to deadlyespecially when temperatures are extremeparticularly for elderly and other vulnerable populations. Emergency managers will be able to use the findings of this research to communicate critical information to the community, even in the direst circumstances, without relying on a techno-fix. A structured focused comparison of three disasters revealed that a high-tech, low-tech, no-tech framework can be implemented successfully and inexpensively. Throughout the three disasters studied, communications methods in the high-tech, low-tech, and no-tech areas were successful in communicating with the public. The thesis recommends that every community be prepared with this three-pronged approach. To go a step further, the study recommends that FEMA consider incorporating the high-low-no-tech approach into its COOP (Continuity of Operations Plan) template, which currently assumes that communications systemsphones, Internet, email, two-way radioswill be operational within 12 hours of activation, an optimistic assumption. A sample implementation plan with cost estimates is included. http://calhoun.nps.edu/handle/10945/39020

KEYWORDS: Blackout, Power Outage, Communications, Information, Social Media, Emergency Management, Radio, COO

MARCH 2014

Electrical and Computer Engineering

RELIABILITY AND CHARACTERIZATION OF HIGH VOLTAGE POWER CAPACITORS

Richard A. Ali–Lieutenant, United States Navy
Master of Science in Electrical Engineering
Advisor: Todd R. Weatherford, Department of Electrical and Computer Engineering
Second Reader: Matthew A. Porter, Department of Electrical and Computer Engineering

Alternative energy products are an increasingly common sight on military bases in the United States. Energy product reliability affects the sustainability and cost-effectiveness of these systems, which must be tested by outside entities to ensure quality. The purpose of this thesis is to perform component level reliability testing on a high voltage power capacitor used in an electrical vehicle solar charging system. A component level characterization was performed to better understand the physical attributes of these capacitors. This investigation identified the expected component lifetime and conditions in which this component will become less reliable. Results are compared to those published by the manufacturer. http://calhoun.nps.edu/handle/10945/41346

KEYWORDS: Capacitors, Characterization, Power, Power Devices, Reliability, Space Charge Limited Current

JUNE 2014

Graduate School of Business and Public Policy

THE USE OF SOCIAL MEDIA TO MAXIMIZE ENERGY PERFORMANCE IN THE UNITED STATES MARINE CORPS

Matthew B. Reed–Lieutenant Commander, United States Navy
Donald M. McIntyre–Lieutenant,United States Navy
Nomer I. Gatchalian–Lieutenant Commander, United States Navy
Master of Business Administration
Advisor: Kathryn Aten, Graduate School of Business and Public Policy
Co-Advisor: Gail Thomas, Graduate School of Business and Public Policy

This research identified social media strategies that could be useful for influencing energy consumption behavior in the United States Marine Corps. We reviewed literature on social learning and media choice that allowed us to develop a media fit/social learning interaction framework for analysis purposes. Using this framework, we conducted a comparative case analysis of eight social media campaigns that varied on factors such as organization structure/culture, program goal, program audience, media used, and program outcome. Results from our analysis show the primary influencers of successful social media campaigns, recommendation(s) for an E2O social media strategy, and a process model explaining how social media can influence behavior change. http://calhoun.nps.edu/handle/10945/42710

KEYWORDS: Marine Corps Expeditionary Energy Office, Social Media, Energy-Efficient Technologies

Electrical and Computer Engineering

INCREASING THE ENDURANCE AND PAYLOAD CAPACITY OF UNMANNED AERIAL VEHICLES WITH THIN-FILM PHOTOVOLTAICS

Seamus B. Carey–Captain, United States Marine Corps
Master of Science in Electrical Engineering
Advisor: Sherif Michael, Department of Electrical and Computer Engineering
Second Reader: Alejandro S. Hernandez, Department of Systems Engineering

Prior research has shown that the endurance of small unmanned aerial vehicles (UAV) can be significantly extended using thin film photovoltaic cells. The different power requirements of the RQ-11B Raven variants are explored in this thesis, and it is demonstrated that a CuInGaS2 (CIGS) solar array adhered to the wing of an RQ-11B not only extends the flight time but also expands the payload capacity of the platform. Power requirements and existing endurance of the digital variant of the RQ-11B were measured to establish a baseline of the platform's performance and validate previous research. A modular wing with an integrated CIGS array was then designed and constructed to be incorporated with the existing power circuitry of the platform. The baseline tests were repeated to determine the power generated by the array and supplied to the digital RQ-11B. It was shown that a solar integrated RQ-11B has a larger payload capacity and extended endurance, while still

maintaining the modular and expeditionary nature of the existing platform. The concept of this research may be applied to all unmanned aerial platforms in order to expand their power generation to operate simultaneous or demanding payloads without stressing the existing power supply. http://calhoun.nps.edu/handle/10945/42594

KEYWORDS: Raven, RQ-11B, UAV, Solar Power, CIGS, Thin Film Photovoltaic

DESIGN AND OPTIMIZATION OF COPPER INDIUM GALLIUM SELENIDE SOLAR CELLS FOR LIGHTWEIGHT BATTLEFIELD APPLICATION

Douglas A. Columbus–Captain, United States Marine Corps
Master of Science in Electrical Engineering
Advisor: Sherif Michael, Department of Electrical and Computer Engineering
Second Reader: Daniel Nussbaum, Department of Operations Research

The design and optimization of higher efficiency Copper Indium Gallium Selenide (CIGS) solar cells are investigated in this thesis. Optimizing the thickness layers of a cell for various band gaps was conducted in order to design a cell that exceeds the current industry efficiency record of 20.8%. Silvaco provides a modeling program called ATLAS that is specifically designed to model semiconductor devices. ATLAS was used to model a CIGS cell that is currently being produced to verify the validity of the model. Various thicknesses were then swept to determine the optimum thickness for a given band gap. Solar spectrum intensity varies by location around the Earth. Optimizing CIGS cells for various band gaps yields higher overall power output when dealing with drastic climate and location variations. Cells for five band gaps ranging from 1.14 eV to 1.69 eV were optimized in this thesis. The highest achieved efficiency was for a band gap of 1.69 eV with an overall theoretical efficiency of 22.4%. http://calhoun.nps.edu/handle/10945/42600

KEYWORDS: CIGS, efficiency, optimization, thickness, band gap, Silvaco, ATLAS

Mechanical and Aerospace Engineering

IMPROVING OPERATIONAL EFFECTIVENESS OF TACTICAL LONG ENDURANCE UNMANNED AERIAL SYSTEMS (TALEUAS) BY UTILIZING SOLAR POWER

Nahum Camacho–Lieutenant, Mexican Navy
Mechanical Engineer & Master of Science in Mechanical Engineering
Advisor: Vladimir N. Dobrokhodov, Department of Mechanical and Aerospace Engineering
Co-Advisor: Kevin D. Jones, Department of Mechanical and Aerospace Engineering
Second Reader: Isaac Kaminer, Department of Mechanical and Aerospace Engineering

This thesis develops, implements, and validates a hybrid energy-harvesting technique that enables extracting energy from the environment by utilizing convective thermals as a source of potential energy, and exploiting solar radiation for photovoltaic (PV) energy to achieve long endurance flight of an autonomous glider. The dynamic behavior of convective thermals, as well as their mathematical models, are studied to determine their motion, while the navigation task is simultaneously solved using a Bayesian search approach that is based on the prior knowledge of the 3D elevation. This study advances an existing technique for detection of thermals by implementing the online identification of the airplane sink rate polar. The glider's climb rate is optimized by implementing a modified thermalling controller, and its performance is compared to an existing method of centering

in thermals. The integration of the energy extracted from the solar radiation is accomplished by the design of an Electrical Energy Management System (EEMS) that safely collects and distributes the energy onboard. The electrical energy is supplied by the semi-rigid mono crystalline silicon solar cells, which are embedded into the skin of the glider's wings without distorting the airfoil. To validate and verify the algorithms developed in MATLAB/Simulink, an interface to a high-fidelity pilot's training flight simulator was designed. Furthermore, the numerical algorithms were integrated onboard a prototype SB-XC glider equipped with solar cells to enable the desired energy-harvesting technique. Flight test results verify the feasibility of the developed algorithms. http://calhoun.nps.edu/handle/10945/42593

KEYWORDS: convective thermals, thermalling control, system identification, photovoltaics, Bayesian search, guidance, navigation, path planning, Electrical Energy Management System, MATLAB/ Simulink, mathematical modeling and simulation

HOT THERMAL STORAGE IN A VARIABLE POWER, RENEWABLE ENERGY SYSTEM

Themba D. Hinke–Lieutenant, United States Navy
Master of Science in Mechanical Engineering
Advisor: Anthony J. Gannon, Department of Mechanical and Aerospace Engineering
Co-Advisor: Anthony G. Pollman, Department of Mechanical and Aerospace Engineering

This thesis outlines the design of a renewable energy heat generation system with thermal storage for DOD facilities. The DOD is seeking to implement an increased percentage of renewable energy systems at its facilities in order to improve energy security and reduce energy costs. The intermittent nature of renewable energy generation, however, presents a major challenge to full implementation. This shortfall can be overcome by targeted facility-scale energy storage that allows for increased use of renewable-only systems. Since a large percentage of the electric energy used in both residential and commercial facilities is for space and water heating, thermal storage is a viable solution. Presented in this thesis is a method for designing, analyzing, and sizing a facility-scale thermal storage system. The results demonstrate thermal storage is a more cost-effective option when compared to alternatives like battery storage. In addition to being cheaper, thermal storage systems are safer, more reliable, and have a longer life cycle. http://calhoun.nps.edu/handle/10945/42645

KEYWORDS: Thermal Storage Design, Renewable Energy, Energy Security, Storage Simulation, Facilities Energy

IGNITION DELAY PROPERTIES OF ALTERNATIVE FUELS WITH NAVY-RELEVANT DIESEL INJECTORS

Andrew J. Rydalch–Ensign, United States Navy
Master of Science in Mechanical Engineering
Advisor: Christopher M. Brophy, Department of Mechanical and Aerospace Engineering
Second Reader: Sanjeev Sathe, Department of Mechanical and Aerospace Engineering

In support of the Navy's Green Fleet Initiative, this thesis researched the ignition characteristics for diesel replacement fuels used with Navy-relevant fuel injectors. A constant-volume combustion chamber was used to simulate Top-Dead-Center conditions of a diesel engine using an ethylene-air preburn with appropriate make-up oxygen. The injection conditions ranged from temperatures of 1,000 K to 1,300 K and densities has high as 14.8 kg/m3. Hydrotreated renewable diesel (HRD) and direct sugar-to-hydrocarbon (DSH) fuels were injected into the combustion chamber using a Sturman research injector, a Yanmar injector, and an Electro Motive Diesel (EMD) injector. The

primary means of data collection was optical emission imaging of laser induced fluorescence of the fuel and broadband emission of the combustion event. The ignition delay was determined using high speed imaging at 50 kHz to determine the time delay between start of injection and start of combustion. The results of the study show that the ignition delay characteristics for the F-76/HRD 50/50 blend are compatible with those of conventional F-76 diesel fuel for both the Yanmar and EMD injectors at the conditions tested. The ignition delay characteristics of the F-76/DSH 50/50 blend fuel for the Yanmar injector were also compatible with those of F-76. http://calhoun.nps.edu/handle/10945/42715

KEYWORDS: F-76, HRD, DSH, CVCC, ignition delay, preburn, diesel injector, alternative fuels

A METHODOLOGY FOR MULTIDISCIPLINARY DECISION MAKING FOR A SURFACE COMBATANT MAIN ENGINE SELECTION PROBLEM

Mustafa G. Tosun
Lieutenant Junior Grade, Turkish Navy
Master of Science in Mechanical Engineering
Advisor: Oleg Yakimenko, Department of Mechanical and Aerospace Engineering
Co-Advisor: Fotis A. Papoulias, Department of Systems Engineering

In the ship design process, delivering optimum performance while reducing development and construction costs are key considerations. A great amount of optimization effort should be done before progressing on a project. When it comes to the main engine selection phase that corresponds to the heart of the ship, the ultimate choice will affect the overall platform. However, the problem of main engine selection is, as is the overall ship design problem in general, basically a multidisciplinary and multicriterion optimization problem. In this project, we will focus on the multicriterion decision-making methodology for a surface combatant main engine selection problem. This study will consist of a collection of systematic approaches to the overall design optimization. The factors that need to be taken into consideration while selecting a main engine for a surface combatant will be discussed. We propose to develop and examine a mathematical model to analyze the main engine selection problem. The mathematical model will be comprehensively formulated, including both quantitative criteria as well as fuzzy systems, to establish an algorithm that will be able to create a unique solution or a set of Pareto solutions to the main engine selection problem. http://calhoun.nps.edu/handle/10945/42742

KEYWORDS: Preliminary Ship Design, Propulsion Plant Selection, Power Plant

Modeling, Virtual Environments and Simulation

ASSESSING THE OPERATIONAL ROBUSTNESS OF THE HOMER MODEL FOR MARINE CORPS USE IN EXPEDITIONARY ENVIRONMENTS

Matthew M. Morse–Captain, United States Marine Corps
Master of Science in Modeling, Virtual Environments and Simulation
Advisor: Daniel Nussbaum, Department of Operations Research
Co-Advisor: Eugene P. Paulo, Department of Systems Engineering
Second Reader: Christian Darken, Department of Computer Science

As the Marine Corps pursues greater energy efficiency in expeditionary operations, the HOMER micropower optimization model provides potential to serve as a powerful tool for improving Marine Corps power planning. The HOMER software was developed for the modeling and simulation of micropower systems over long periods of time. Although a deterministic model, HOMER uses stochastic input data, specifically solar irradiance, temperature, and load profiles. HOMER simulation fidelity is therefore affected by the inter-annual variability of these profiles. This research quantifies HOMER robustness with regard to solar irradiance and tem-perature profile variability through full-factorial experimental designs. The effect of shortening HOMER simulation duration on the variability of HOMER simulation outputs is also investigated, and though statistically significant, the resulting increase in variability is not large enough to preclude the use of HOMER for expeditionary operations. This thesis also demonstrates how HOMER can assist in developing power planning doctrine, showing that the fuel consumption benefits of using multiple generators of different sizes is no longer present once a renewable energy asset is added to the micropower system. This analysis of HOMER's robustness and operational potential provides insight for improving the Marine Corps' use of HOMER for power planning in an expeditionary environment. http://calhoun.nps.edu/handle/10945/42692

KEYWORDS: micropower system, solar irradiance, inter-annual variability, simulation, design of experiments, deterministic model

Operations Research

STUDY OF NAVAL AIR STATION OPERATIONS TO REDUCE FUEL CONSUMPTION

Adam V. GableMajor, United States Marine Corps
Master of Science in Operations Research
Advisor: Roberto Szechtman, Department of Operations Research
Second Reader: Michael Dixon, Graduate School of Business and Public Policy

Naval aviation accounts for 54% of all naval fuel usage. With such a large footprint, even small reductions in fuel consumption can have a significant impact on the bottom line. Recognizing this fact, the Chief of Naval Operations has targeted naval aviation to achieve a 4% reduction in non-mission fuel burn without adversely affecting mission execution or safety. In this thesis, we model ground operations at Naval Air Station (NAS) Oceana and NAS Lemoore to identify and reduce the time an aircraft spends with engines online during post-flight operations. Specifically, by reducing the processes performed while conducting hot brake checks and reducing resources required at the hot skids, we are able to save over $8 million at NAS Oceana and Lemoore alone. In addition, we have identified zero-cost coordination efforts that increase synchronization of fuel truck delivery to their consumers, such as noting refueling intentions on schedules to allow fuel truck managers to allocate trucks more efficiently, leading to additional savings. We provide recommendations specific to each base and recommendations that can be adopted fleet-wide. Finally, we identify that the current allocation of aircraft among bases is suboptimal and provide policy recommendations that would improve overall readiness. http://calhoun.nps.edu/handle/10945/42629

KEYWORDS: Simulation, optimization, aircraft allocation, fuel reduction, naval aviation

Physics

POWER SYSTEMS AND ENERGY STORAGE MODELING FOR DIRECTED ENERGY WEAPONS

Jeremy E. Sylvester
Lieutenant, United States Navy
Master of Science in Physics
Co-Advisor: William B. Colson, Department of Physics
Co-Advisor: Joseph A. Blau, Department of Physics
Second Reader: Keith R. Cohn, Department of Physics

As the United States Navy makes leaps forward in technology that is being deployed onboard ships, there is a growing need for research to predict what will be needed to integrate new weapon systems with old. Directed energy weapons are being deployed onboard naval platforms starting in 2014, and this paper seeks to answer the question of what energy storage, if any, must be used in conjunction with high-power lasers in order to integrate them with current ships in the fleet. Four energy storage methods are being researched. These storage medias will allow a ship to fire multiple shots from a high-powered laser without taxing the ship's electrical system. Lead acid batteries, lithium ion batteries, supercapacitors, and flywheels each have their benefits and drawbacks, and those will be discussed. A computer simulation has been developed and used to represent a DDG-51 Arleigh Burke class destroyer and each of the four energy storage methods. This simulation was run repeatedly with different powered high-powered lasers in order to produce a recommendation for what types of energy storage would be necessary to operate these devices onboard ships. http://calhoun.nps.edu/handle/10945/42734

KEYWORDS: Energy storage, flywheel, battery, directed energy weapons, laser systems, power systems

Security Studies

JAPAN'S AND CHINA'S ECONOMIC GROWTH AND ENERGY HUNGER IN COMPARATIVE AND HISTORICAL PERSPECTIVE

Oliver-John Steensen-Schulz–Major, German Army
Master of Arts in Security Studies (Far East, Southeast Asia, and The Pacific)
Advisor: Sophal Ear, Department of National Security Affairs
Second Reader: Naazneen H. Barma, Department of National Security Affairs

Like Japan in the 1970s, the People's Republic of China is currently facing economic growth measured in double-digit numbers. As both countries have faced, and continue to face, energy resource scarcity to feed their economic growth, they have reached out to the world to get these resources. How did Japan and how does today's China ensure access to needed energy resources like oil and gas? How can these efforts be viewed according to international relations theory? Both countries use oil-producing companies, financial/development aid, and strong government support directly to domestic companies and within accompanying policies and negotiations to support their companies. The Japanese government tapped economic growth to become a global economic power, but is China more interested in using economic growth to maintain the ruling party's power and the government itself? In terms of internationall relations theory, Japan and China show a realist approach in feeding their energy hunger, with the difference that Japan was and still is much more

integrated into a variety of international organizations. This difference shows a bit of a liberal-institutional approach, but with realist goals set by the state. Although this thesis makes this comparison and applies international relations theory for a better insight into the economic development and long-term goals of Japan and China, it cannot specifically predict China's future relationship with resource-rich countries and the international community. http://calhoun.nps.edu/handle/10945/42732

KEYWORDS: People's Republic of China, Japan, international relations theory, energy resources, economic growth, development aid, foreign policy, loans-for-oil policy, UN sanctions, conditional aid, access to resources

Systems Engineering

LIGHTENING THE LOAD OF A USMC RIFLE PLATOON THROUGH ROBOTICS INTEGRATION

Sian E. Stimpert–Lieutenant, United States Navy
Master of Science in Systems Engineering
Advisor: Alejandro Hernandez, Department of Systems Engineering
Co-Advisor: Richard C. Millar, Department of Systems Engineering

With the increase of the loaded weight that a Marine carries, the integration of robotics is a significant point of interest to the United States Marine Corps, especially to the Expeditionary Energy Office. Through the use of the agent-based modeling and simulation application, Pythagoras, robots are integrated into a Marine Expeditionary Unit's rifle platoon to alleviate the burden on each Marine. This study examines the rifle platoon's energy and power consumption, operational reach, and operational effectiveness for a scouting and patrolling mission. A systems engineering methodology results in a tradeoff analysis on the rifle platoon's success, relative to the number of integrated robots. Integrating six robots in a rifle platoon can improve the platoon's ability to fulfill its mission, while supporting the Marine Corps' energy strategy. In the context of energy initiatives, this research forms the baseline for investigating the impact of robot integration in Marine combat operations through simulations. http://calhoun.nps.edu/handle/10945/42733

KEYWORDS: Simulation, modeling, integration, robotics, systems engineering, agent-based, Pythagoras, energy

DECEMBER 2014

Graduate School of Business and Public Policy

SEA WATER AIR CONDITIONING AT NAVAL BASE GUAM: COST-BENEFIT ANALYSIS AND ACQUISITION STRATEGY

Kevin Crisson–Lieutenant Commander, United States Navy
Jason Grammar–Lieutenant, United States Navy
Peter Leestma–Captain, United States Air Force
Master of Business Administration
Advisor: Daniel Nussbaum, Department of Operations Research
Co-Advisor: Keith Snider, Graduate School of Business and Public Policy

The purposes of this research are to determine whether it is financially feasible and attractive to install sea water air conditioning (SWAC) at Naval Base (NB) Guam, which the Naval Facilities Engineering Command currently deems to be true; to develop an acquisition strategy that NB Guam would be able to use to procure a SWAC system; and to identify any environmental obstacles associated with installing a SWAC system at NB Guam. This includes environmental impact studies and potential long-term schedule effects of environmental research. This research provides the analytic underpinning for the SWAC-driven reduction of electricity consumption at a significant number of naval facilities, and it provides a significant contribution towards meeting the Secretary of the Navy's renewable energy goals. http://calhoun.nps.edu/handle/10945/44542

KEYWORDS: sea water air conditioning, SWAC, Naval Base Guam, energy saving performance contract, ESPC

ENERGY RESILIENCY FOR MARINE CORPS LOGISTICS BASE PRODUCTION PLANT BARSTOW

Christopher Czumak–Captain, United States Marine Corps
J. Christian Woodside–Lieutenant, United States Navy
Master of Business Administration
Advisor: Nicholas Dew, Graduate School of Business and Public Policy
Second Reader: Philip Candreva, Graduate School of Business and Public Policy

The purpose of this thesis is to examine feasible microgrid and on-site energy generation options to provide power infrastructure resiliency aboard Production Plant Barstow (PPB), such that the site has suitable standalone power to endure emergency or catastrophic situations. The main objective is to analyze the best options available to create resiliency for continued PPB depot maintenance functions during temporary or catastrophic natural or adversarial disruptions to its power infrastructure. First, we collect and normalize energy and environmental data specific to PPB and Barstow, CA. Second, we analyze the cost and suitability of renewable and alternative energy sources as well as microgrid technology. Last, we determined the value of PPB's energy security and created energy portfolio options based on various sensitivity analyses. The result is an analysis framework for achieving resiliency at PPB and additional Marine Corps Logistics Command (MCLC) production plants. This study provides an analysis of PPB's value of electrical energy security (VEES), offers recommendations for selecting a cost-effective, resilient and scalable alternative energy portfolio, and creates a levelized cost for a microgrid and its components by combining data from various credible sources in order to fully understand appropriate investment criteria. Additionally, it provides feasible

energy options that when aligned reduce PPB's greenhouse emissions and dependencies on limited resources, increase energy efficiency and use of renewable energy (RE) and alternative fuel, and create energy security in accordance with Department of Defense (DoD) mandates and the Marine Corps' stated objectives for its installation energy strategy. This analysis will assist the Marine Corps to determine specific actions to create energy resiliency programs at PPB and future sites. http://calhoun.nps.edu/handle/10945/44546

KEYWORDS: renewable energy, energy security, Marine Corps installations, value of energy security, modern portfolio theory, solar, photovoltaic, wind, biomass, waste-to-energy, energy planning, energy strategy, value of electrical energy security, customer damage function, cost of interruption, probability of interruption

SOLAR PHOTOVOLTAIC AND LIQUID NATURAL GAS OPPORTUNITIES FOR COMMAND NAVAL REGION HAWAII

Austin Henne–Lieutenant, United States Navy
Master of Business Administration
Advisor: Nicholas Dew, Graduate School of Business and Public Policy
Co-Advisor: Daniel Nussbaum, Department of Operations Research

This thesis examines the costs and benefits of two onsite energy opportunities for Command Naval Region Hawaii (CNRH) and the surrounding region. The project analyzes a proposed 50-MW solar photovoltaic (PV) system on West Loch Peninsula in Pearl Harbor, Hawaii, and the economic impacts of a proposed liquid natural gas (LNG)-import terminal on Waipu Peninsula in Pearl Harbor, using net present value (NPV) and cost benefit analyses. CNRH is considering collaboration with Hawaiian electric companies to pursue the proposed PV plant and the LNG terminal in order to meet Hawaiian clean energy initiative requirements for producing 40 percent renewable energy by 2030. The goal of this project is to calculate the economic impacts an LNG-import terminal might have on solar PV and potential indirect impacts of pursuing both projects. http://calhoun.nps.edu/handle/10945/44576

KEYWORDS: solar photovoltaic, renewable energy, Command Naval Region Hawaii, West Loch, Waipu, liquid natural gas, Hawaii electric company

BUDGET SAVINGS THROUGH THE RESPONSIBLE USE OF ENERGY IN NAVY PRIVATIZED HOUSING COMMUNITIES

Jeffrey Sachinski–Lieutenant, United States Navy
Rudolph Cook–Lieutenant Commander, United States Navy
Beth Matteson–Lieutenant, United States Navy
Master of Business Administration
Advisor: Daniel Nussbaum, Department of Operations Research
Co-Advisor: Doug MacKinnon, Department of Information Sciences

In 1996, Congress authorized the Military Housing Privatization Initiative, which led to the increase in basic allowance for housing (BAH) for active duty members to achieve zero out-of-pocket housing expenses while living in military privatized housing. Privatized housing residents are not fully incentivized to conserve energy. Average energy costs, taken over like sized groups, are used as a baseline to justify the amount paid to the actual energy provider out of BAH proceeds collected from the service member. Water baselines do not exist in privatized housing, resulting in zero incentive to conserve water. We propose that the responsible use of energy incentive options can be promoted using a different system. Our approach pays members a direct subsidy equal to a fair market value of

the rental property, coupled with a utilities model which is based on baseline utility costs and family size. This approach will effectively and efficiently utilize the Navy BAH system while reducing overall costs to the Navy. Future research could be conducted on the feasibility of expanding our recommendations to encompass all services. http://calhoun.nps.edu/handle/10945/44661

KEYWORDS: basic allowance for housing (BAH), basic allowance for quarters (BAQ), variable housing allowance (VHA), military privatized housing, Military Housing Privatization Initiative (MHPI), energy conservation

Electrical and Computer Engineering

MODELING A LINEAR GENERATOR FOR ENERGY HARVESTING APPLICATIONS

Dominic Simone–Lieutenant, United States Navy
Master of Science in Electrical Engineering
Advisor: Alexander L. Julian, Department of Electrical and Computer Engineering
Second Reader: Roberto Cristi, Department of Electrical and Computer Engineering

The intent of this research is to draw attention to linear generators and their potential uses. A flexible model of a linear generator created in MATLAB Simulink is presented. The model is a three-phase, 12-pole, non-salient, synchronous permanent magnet linear generator with a non-sinusoidal back electromotive force (EMF) but could easily be adapted to fit any number of poles or any back EMF waveform. The emerging technologies related to linear generators, such as wave energy converters and free-piston engines, are explained. A selection of these technologies is generically modeled, and their results are discussed and contrasted against one another. The model clearly demonstrates the challenges of using linear generators in different scenarios. It also proves itself a useful tool in analyzing and improving the performance of linear generators under a variety of circumstances.
http://calhoun.nps.edu/handle/10945/44669

KEYWORDS: linear generator, permanent magnet, synchronous machine, non-sinusoidal, Simulink model, rotor reference frame, wave energy converter, free-piston engine

Mechanical and Aerospace Engineering

CONTROL STRATEGY: WIND ENERGY POWERED VARIABLE CHILLER WITH THERMAL ICE STORAGE

The following paper has been recognized as an outstanding thesis by its department.

Rex Boonyobhas–Commander, United States Navy
Master of Science in Mechanical Engineering
Advisor: Anthony Gannon, Department of Mechanical and Aerospace Engineering
Co-Advisor: Anthony Pollman, Department of Mechanical and Aerospace Engineering

This study commissioned a variable speed chiller system powered by renewable energy with ice thermal storage. A control strategy was also developed that matched the chiller load to any available renewable power. These solutions will allow the Department of Defense to move away from the traditional, electrical-focused, energy storage methods, such as batteries, to targeted solutions for large energy uses, specifically cooling. This research required developing a software program to

extract data from a micro-grid. In order to effectively use intermittent renewable power, the researcher created a control algorithm for operating the variable speed chiller and used a monitoring system to match the load to the power production. The data demonstrated that wind energy at the Turbopropulsion Laboratory was intermittent and decreased from summer to fall. The study also created a model to simulate a three-blade vertical-axis wind turbine and compared the results to similar published data. The ANSYS CFX simulation results showed that the NACA0018 blade profile best matched the published result and was, thus, selected for additional turbulence modeling. At speeds less than or equal to 10 m/s, the best turbulence for modeling the turbine was the shear stress transport model; at speeds greater than 10 m/s, standard k-epsilon provided the closer correlation. http://calhoun.nps.edu/handle/10945/44525

KEYWORDS: thermal storage, renewable energy, energy security, storage simulation, facilities energy

Physics

MEMS-BASED WASTE VIBRATION AND ACOUSTIC ENERGY HARVESTERS

Timothy Householder–Lieutenant Commander, United States Navy
Master of Science in Physics
Advisor: Dragoslav Grbovic, Department of Physics
Co-Advisor: Bruce Denardo, Department of Physics

Every machine vibrates and emits noise. This is unused energy that with an appropriate mechanism, can be returned to the system. Utilizing an array of piezoelectric microelectromechanical systems (MEMS) devices to harvest this otherwise wasted energy, it is possible to improve the efficiency of any number of mechanical devices. Piezoelectricity is the mechanism by which certain crystalline structures generate electric potential when under strain or conversely, deform when subjected to an electric potential. It is this first effect that is important to this application. Though each MEMS device will generate a very small amount of power, a 1 m^2 area can contain an array of millions of these devices. Energy harvesting, conservation, and efficiency are all key Department of Defense (DOD) priorities, and the universal application of these devices makes them ideal for any expeditionary platform such as ships, aircraft, and automobiles. This thesis designs and tests the first generations of acoustic and vibrational piezoelectric MEMS devices, including time-dependent finite element models, microfabrication processes, and the initial attempts at characterization and optimization. http://calhoun.nps.edu/handle/10945/44583

KEYWORDS: MEMS, energy harvesting, piezoelectric, resonator

Systems Engineering

MARINE CORPS EXPEDITIONARY RIFLE PLATOON ENERGY BURDEN

Thomas Atkinson–Lieutenant Colonel, United States Marine Corps
Master of Science in Engineering Systems
Advisor: Richard Millar, Department of Systems Engineering
Co-Advisor: Warren Vaneman, Department of Systems Engineering

In 2009, the commandant of the Marine Corps declared energy a top priority and created the U.S. Marine Corps (USMC) Expeditionary Energy Office to develop an energy strategy to reduce and optimize energy usage throughout the Marine Corps. This thesis examines the operational tasks and capabilities that drive the current USMC rifle platoon's energy burdens using an Expeditionary Warrior 2012 war-game scenario. The primary conclusion of the research is that increasing the platoon's ability to carry supplies and developing standardized, rechargeable batteries offers the USMC opportunities to reduce energy at the platoon level. This thesis recommends that the USMC should investigate the use of robotic transport systems and unmanned aerial vehicles to reduce the number of sustainment flights required of large aircraft. It also recommends further research should be conducted to calculate the energy usage at the company level, analyzing robotic solutions and standardized batteries to reduce energy at the platoon level and conducting analysis for water reduction. http://calhoun.nps.edu/handle/10945/44514

KEYWORDS: Marine rifle platoon, Marine expeditionary energy, Marine rifle platoon mission essential tasks, expeditionary energy, water and waste (E2W2)

EVALUATION OF SYSTEM ARCHITECTURES FOR THE ARMY AVIATION GROUND POWER UNIT

Kevin Alexandre–Civilian, Department of the Army
Master of Science in Systems Engineering
Advisor: Walter Owen, Department of Systems Engineering
Second Reader: J. Marc Aparicio, Department of Systems Engineering

Ground support equipment is critical to the success of Army aviation. As the Aviation Ground Power Unit evolves or is replaced, it will be necessary to reduce life cycle costs and improve availability. This thesis explores the requirements and offers potential architectures and component selection to satisfy the Army Aviation Ground Power Unit's requirements while increasing value. Using the current system as a baseline, alternatives were compared using performance, mass, envelope, reliability, and life cycle costs. The power plant proved to be the most important component in the architectures examined. Power plant influence on the life cycle cost of the system was the dominant factor among the selection criteria; fuel and power plant maintenance costs were the largest contributors to system life cycle costs. The research concluded that architectures with diesel engine power plants are preferred even though these architectures have an inherent mass risk and require greater interaction between aviation and ground maintenance activities. http://calhoun.nps.edu/handle/10945/44510

KEYWORDS: Aviation Ground Power Unit, ground support equipment, cost analysis

SEPTEMBER 2014

Electrical and Computer Engineering

MODELING AND IMPLEMENTING A DIGITALLY EMBEDDED MAXIMUM POWER POINT TRACKING ALGORITHM AND A SERIES-LOADED RESONANT DC-DC CONVERTER TO INTEGRATE A PHOTOVOLTAIC ARRAY WITH A MICRO-GRID

Troy D. Bailey–Lieutenant Commander, United States Navy
Master of Science in Electrical Engineering
Co-Advisor: Giovanna Oriti, Department of Electrical and Computer Engineering
Co-Advisor: Alexander L. Julian, Department of Electrical and Computer Engineering

A DC-DC converter with an embedded digital maximum power point tracking (MPPT) algorithm for a photovoltaic (PV) application is presented in this thesis. The topology centers around a series-loaded resonant (SLR) converter using galvanic isolation that interfaces a PV array with a storage battery connected to the DC bus of an existing micro-grid. The SLR converter operates in discontinuous conduction mode to minimize the switching losses and for the linear relationship between switching frequency and converter output current. This feature allows for multiple SLR converters to be paralleled, improving the overall efficiency of a PV system by eliminating a central converter and instituting the concept of multiple micro-converters. The perturb and observe MPPT algorithm employed uses a single voltage sensor and schedules a switching frequency based on the PV array power feedback. The performance of the MPPT algorithm is compared to a similar algorithm that uses both a current and voltage sensor. In this thesis, the SLR converter control system was simulated, designed, and implemented in the laboratory. The experimental measurements show that the SLR converter presented is an ideal topology for a PV application. http://calhoun.nps.edu/handle/10945/43870

KEYWORDS: Photovoltaic, maximum power point tracking, series-loaded resonant converter, DC micro-grid

UTILIZING AN ENERGY MANAGEMENT SYSTEM WITH DISTRIBUTED RESOURCES TO MANAGE CRITICAL LOADS AND REDUCE ENERGY COSTS

David J. Gustafson–Major, United States Marine Corps
Master of Science in Electrical Engineering
Advisor: Giovanna Oriti, Department of Electrical and Computer Engineering
Co-Advisor: Alexander L. Julian, Department of Electrical and Computer Engineering

Energy security is critical to the DOD and can be achieved using different methods, but for DOD installations cost effectiveness must be taken into consideration when evaluating energy security goals. Energy Storage Systems (ESSs) have a wide range of associated technologies as well as large differences in cost and capabilities. This study examines the cost effectiveness of utilizing an ESS to perform peak shaving with an Energy Management System (EMS). An EMS used with an ESS can perform several functions that can be beneficial to the grid. These functions include peak shaving, conducting power factor correction, matching critical load to most efficient distributed resource, and islanding a system during commercial grid disruption. While utilizing an ESS within a microgrid allows several benefits, to include peak shaving, the ability to utilize photovoltaic arrays during islanding, and power factor correction, the implementation of the ESS by itself is likely to prove cost

prohibitive. The DOD requires energy projects to have net savings over the life cycle of the project and in areas without high differential between peak power and off-peak power, this goal will be difficult to achieve. http://calhoun.nps.edu/handle/10945/43921

KEYWORDS: Energy Management System, Energy Storage Systems, Energy Storage

REACTIVE POWER COMPENSATION USING AN ENERGY MANAGEMENT SYSTEM

Michael V. Prato–Major, United States Marine Corps
Master of Science in Electrical Engineering
Advisor: Alexander L. Julian, Department of Electrical and Computer Engineering
Co-Advisor: Giovanna Oriti, Department of Electrical and Computer Engineering

A significant contributor to higher energy costs and reduced energy efficiency is the reactive power demand on the grid. Inductive power demand reduces power factor, increases energy losses during transmission, limits real power supplied to the consumer, and results in higher costs to the consumer. Compensating for a reactive power demand on the grid by providing reactive power support to the power distribution system creates energy efficiency gains and improves cost savings. One method of compensating for reactive power is by incorporating an energy management system (EMS) into the power distribution system. An EMS can monitor reactive power requirements on the grid and provide reactive power support at the point of common coupling (PCC) in the power distribution system in order to increase energy efficiency. The use of an EMS as a current source to achieve a unity power factor at the grid is demonstrated in this thesis. The power factor angle was determined using a zero-crossing detection algorithm. The appropriate amount of compensating reactive current was then injected into the system at the PCC and controlled using closed-loop current control. The process was simulated using Simulink and then validated in the laboratory using the actual EMS hardware. http://calhoun.nps.edu/handle/10945/43982

KEYWORDS: Reactive power, reactive power compensation, reactive power control, reactive power demand, power factor, power factor improvement, power factor correction, energy management system, EMS, power loss, reactive power loss, zero-crossing detection, closed-loop current control, energy efficiency, energy cost savings

ANALYSIS OF AC LOW-VOLTAGE ENERGY HARVESTING

Dmitry Shvets–Lieutenant, United States Navy
Master of Science in Electrical Engineering
Advisor: Alexander L. Julian, Department of Electrical and Computer Engineering
Second Reader: Giovanna Oriti, Department of Electrical and Computer Engineering

Piezoelectricity is a material property that generates an electric charge proportional to the mechanical stress placed on the material. This phenomenon was first discovered by the Curie brothers in 1880. This material property gives the ability to turn vibrations into an electrical waveform, but power electronics is necessary to harness this low-level energy. AC power is often produced at the power plant level in modern society; however, low voltage AC power is widely available in vibrational form. The U.S. Navy may be able to utilize piezoelectric technology to harness wasted vibrational energy. Some of these applications include inserting a piezoelectric harvester in shoes to supply small amounts of power to cell phones or utilizing motion energy to provide power to iPod chargers. The power electronics that provides full bridge rectification and step down conversion, which achieves AC-DC power harvesting, is discussed. Also discussed is a breakdown of possible applications for such a device as well as the benefits of turning AC power into DC. A Linear Technology LTC-3588-

1 integrated circuit was simulated in software and demonstrated in hardware. The hardware experiment showed that the software accurately predicted the performance of the chip. http://calhoun.nps.edu/handle/10945/43719

KEYWORDS: Renewable energy, Piezoelectric, Energy harvesting, buck converter

Mechanical and Aerospace Engineering

AN ASSESSMENT OF HYDROGEN AS A MEANS TO IMPLEMENT THE UNITED STATES NAVY'S RENEWABLE ENERGY INITIATIVE

Jason D. Paradis–Lieutenant, United States Navy
Master of Science in Mechanical Engineering
Advisor: Young W. Kwon, Department of Mechanical and Aerospace Engineering
Co-Advisor: Maximilian F. Platzer, Department of Mechanical and Aerospace Engineering

In response to Presidential Executive Order 13514, the Secretary of the Navy established the 1GW Task Force to meet the Navy's goal of producing at least half of shore-based energy requirements from alternative energy sources. In this thesis, the question is investigated whether renewably produced hydrogen can contribute to the accomplishment of this goal. It is known that ocean wind energy has yet to be fully exploited as a renewable energy source. It is therefore proposed to use sailing ships equipped with hydroturbines and electrolysers to convert this ocean wind energy into storable energy in the form of hydrogen. The hydrogen is then compressed and transported to nearby naval facilities. The technical and economic aspects of this energy-ship concept are analyzed by estimating the drag of the sailing ships, sail lift, and the power requirements of the desalinator, electrolyser, and hydrogen compressor. A previous study of the power requirements of the 76 inhabitants of Grimsey Island, near Iceland, is used to compare the energy-ship power production method with wind turbine based hydrogen production. It is found that 13 Catalina 36 sized, autonomously operating, sailboats can provide the Grimsey Island power at an economically competitive cost with the previously proposed wind-hydrogen method. http://calhoun.nps.edu/handle/10945/43972

KEYWORDS: hydrogen, energy-ship, renewable energy

AN OPTICAL METHOD FOR MEASURING INJECTION TIMING IN DIESEL ENGINES, USING A SINGLE PORT

Sandra J. Wyman–Lieutenant, United States Navy
Master of Science in Mechanical Engineering
Advisor: Knox T. Millsaps, Department of Mechanical and Aerospace Engineering
Co-Advisor: Douglas L. Seivwright, Department of Mechanical and Aerospace Engineering

This thesis is the design of a laser-induced fluorescence technique for use in the characterization of the fuel injection delay of various fuels, due to differences in bulk modulus. The technique is designed to work with an operational diesel engine having readily accessible glow-plug ports. The optical adapter designed for use through the glow-plug port is used as both the transmitting port for the excitation signal and the receiving port for the fluorescence signal. The prototype system was installed on a Detroit Diesel 3–53 two-stroke diesel engine. The beginning of the injection cycle is measured by a proximity probe set to detect injector compression to the point where the injector chamber is sealed. The actual entry of fuel into the cylinder is measured using laser induced

fluorescence of an organic laser dye seeded fuel, excited by a 532-nm laser. The time/crank angle delay from the start of fuel compression to fuel entry into the cylinder can then be correlated to bulk modulus and cetane number. The combustion event can also be detected using the same optics and its timing correlated with known fuel properties. http://calhoun.nps.edu/handle/10945/44031

KEYWORDS: Hydroprocessed Renewable Diesel, HRD, Alternative Fuel Blends, F-76, Diesel Engine Combustion, Diesel Engine Injection Timing, Cetane Number, Bulk Modulus, Laser Fluorescence Measurement, Pyrromethene 597, Diesel Engine Combustion Timing, Laser-Induced Fluorescence, Fiber Optic, Sapphire Optic, Spectroscopy

Operations Research

ALTERNATIVE PRACTICES TO IMPROVE SURFACE FLEET FUEL EFFICIENCY

Dustin K. Crawford–Lieutenant, United States Navy
Master of Science in Operations Research
Advisor: Daniel Nussbaum, Department of Operations Research
Second Reader: Gerald Brown, Department of Operations Research

We explore the United StatesNavy's surface fleet policies and practices that, if changed, could provide significant fuel savings for fossil fuel ships. Recent and potential future budget cuts give fuel conservation and efficiency extreme importance. The policies and practices explored incur no overhead cost, and to reap the benefits of these changes, we simply need to prudently change in the way we operate. Conducting drift operations 10% of the nights while underway can save the Navy $14.1 million per year, and conducting single-generator operations 25% of the time underway can save $27.4 million per year. Removing the moving window requirement during a transit can reduce fuel consumption by as much as 21%. Utilizing the Transit Fuel Planner shows fuel savings as high as 19% during transits. Lowering the minimum fuel safety levels in 5th and 7th Fleets from 60% to 50% reduces fuel consumption for Military Sealift Command ships by $18.5 million per year. Changing or removing outdated policies and practices utilized by the surface fleet can save significant amounts of fuel, and therefore dollars, and can be done with the stroke of a pen. http://calhoun.nps.edu/handle/10945/43897

KEYWORDS: Fuel, efficiency, surface fleet, fuel savings, fuel consumption, Military Sealift Command, Transit Fuel Planner, Replenishment At Sea Planner

OPTIMIZING MICROGRID ARCHITECTURE ON DEPARTMENT OF DEFENSE INSTALLATIONS

Nicholas A. Ulmer–Lieutenant Commander, United States Navy
Master of Science in Operations Research
Advisor: Emily Craparo, Department of Operations Research
Second Reader: Dashi Singham, Department of Operations Research

Energy managers are faced with the challenge of upgrading their installation microgrids in a tight fiscal environment, while meeting the challenges of incorporating higher percentages of renewable energy sources and providing better energy assurance during commercial grid failures. Incorporating renewable sources of energy into a microgrid is challenging due to the intermittent nature of supply. Using historical solar data and simulated forecasts for wind data, we formulate and exercise a capital planning optimization model designed to choose the best subset of existing and potential energy

sources to maximize microgrid islanding time. Islanding time is defined as the amount of time demands can be met without connection to the commercial power grid, and it is one measure of an installation's power resiliency. Using sensitivity analysis, we show quantitatively how increases in the capital planning budget has a direct positive impact on islanding time. However, the model also identifies areas where large increases in budget yield proportionally smaller returns in islanding time. Additionally, energy storage can provide increases in islanding time, but there are diminishing returns as the storage capacity is increased. Finally, we quantitatively show that increasing reliance on renewable power decreases sensitivity to changes in the price of fuel. http://calhoun.nps.edu/handle/10945/44023

KEYWORDS: Energy, mircrogrid, capital planning, optimization, solar, wind, renewables

Space Systems

NPS SOLAR CELL ARRAY TESTER CUBESAT FLIGHT TESTING AND INTEGRATION

Joseph K. Helker–Lieutenant, United States Navy
MASTER OF SCIENCE IN
SPACE SYSTEMS OPERATIONS
Master of Science in Space Systems Operations
Advisor: James H. Newman, Space Systems Academic Group
Second Reader: Stephen H. Tackett, Space Systems Academic Group

The Naval Postgraduate School Solar Cell Array Tester (NPS-SCAT) is the first CubeSat for the Naval Postgraduate School (NPS). The NPS-SCAT mission was designed to measure solar cell performance degradation in low earth orbit. NPS-SCAT serves as a pathfinder for future NPS CubeSat missions. This thesis documents the pre-flight NPS-SCAT battery analysis, power budget, vibration analysis, beacon antenna integration evaluation, and conformal coat study. Some data from the flight is presented, which validates the pre-flight power budget analysis. http://calhoun.nps.edu/handle/10945/43925

KEYWORDS: solar cell array tester, CubeSat, Naval Postgraduate School, NPS-SCAT, solar cell, integration, vibration testing, Clydespace battery, ORS-3, I-V curve, sun sensor, space systems

Systems Engineering

SYSTEMS ENGINEERING TECHNOLOGY READINESS ASSESSMENT OF HYBRID-ELECTRIC TECHNOLOGIES FOR TACTICAL WHEELED VEHICLES

Eddie E. McCown–Civilian, Department of the Air Force
Master of Science in Systems Engineering Management
Advisor: Charles C. Pickar, Graduate School of Business and Public Policy
Second Reader: Bonnie Young, Department of Systems Engineering

The Department of Defense is the largest federal government consumer of fossil fuel. The military has been severely limited by the burden of petroleum-based fuel technologies, which have greatly hindered the military's ability to conduct operational missions in support of worldwide commitments. The military's interoperability is hindered by an insatiable worldwide demand for fuel supply and a

profound dependence on other countries, especially hostile nations for fuels. Improvements in technology are critical to meeting energy goals. One solution could be the use of hybrid-electric vehicles. Hybrid-electric technology (HET) offers significant opportunities for the military to meet the growing demands for reduced fuel consumption and increased combat vehicle performance. With fuel costs as high as $500 per gallon in the battlefield, according to Gen. James T. Conway, former Commandant of theMarine Corps, it is astonishing that hybrid-electric (HE) military tactical wheeled vehicles have not been deployed. This study presents a technology readiness assessment of the benefits and challenges relative to cost, maturity and technical complexity of the HE system for military vehicle applications. It describes the potential benefits offered should the military make the leap into HET. http://calhoun.nps.edu/handle/10945/43955

KEYWORDS: Hybrid-Electric Technology, Hybrid-Electric Vehicles, Energy Savings

MARCH 2015

Systems Engineering

INCREASING THE KILL EFFECTIVENESS OF HIGH ENERGY LASER (HEL) COMBAT SYSTEM

Cohort 311-133O/High Energy Laser Battle Damage Assessment Team
Master of Science in Systems Engineering and Master of Science in Engineering Systems

A kill assessment system built into a High Energy Laser (HEL) Combat System will provide the U.S. Navy with a method to efficiently engage threats with an HEL effector, improve the weapon scheduling function, and help manage ship's limited power resources. Near real-time Battle Damage Assessment (BDA) and Dwell Time determinations make up the new kill assessment system, which is simply called the BDA System. This system is a critical force-multiplier for ship survivability by limiting all HEL-target engagements to the minimum dwell time required for threat mitigation, while providing a mission kill interface to the Combat System for a calculated decision point to either re-engage the same threat or engage the next assigned target. This new BDA system concept for a shipboard HEL Combat System was analyzed in order to verify an expected increase in overall system efficiency and performance. The minimum desired increase of threat engagement efficiency was set at 25%. The proof of concept model developed for this project shows that adding a BDA system function to the HEL Combat System causes the system to exceed this threshold of efficiency. http://calhoun.nps.edu/handle/10945/45247

KEYWORDS: high energy laser, battle damage assessment, layered defense, asymmetric threats, directed energy warfare, swarm, surface ship combat system assessment, anti-access area denial

JUNE 2015

Applied Mathematics

OPTIMAL DESIGN OF PIEZOELECTRIC MATERIALS FOR MAXIMAL ENERGY HARVESTING
Russell Nelson–Captain, United States Army
Master of Science in Applied Mathematics
Advisor: Hong Zhou, Department of Applied Mathematics
Second Reader: Susan Sanchez, Department of Operations Research

The military's dependence on fossil fuels for electric power production in isolated settings is both logistically and monetarily expensive. Currently, the Department of Defense is actively seeking alternative methods to produce electricity, thus decreasing dependence on fossil fuels and increasing combat power. We believe piezoelectric generators have the ability to contribute to military applications of alternative electrical power generation in isolated and austere conditions. In this paper, we use three and six variable mathematical models to analyze piezoelectric generator power generation capabilities. Using mk factorial sampling, nearly orthogonal and balanced Latin hypercube (NOBLH) design, and NOBLH iterative methods, we find optimal solutions to maximize piezoelectric generator power output. We further analyze our optimal results using robustness analysis techniques to determine the sensitivity of our models to variable precision. With our results, we provide analysts and engineers the optimal designs involving material parameters in the piezoelectric generator, as well as the generator's environment, in order to maximize electric output. http://calhoun.nps.edu/handle/10945/45913

KEYWORDS: piezoelectric power optimization, nearly orthogonal and balanced Latin hypercube design, factorial sampling, nearly orthogonal and balanced Latin hypercube design iterative method, robustness analysis

Graduate School of Business and Public Policy

RENEWABLE ENERGY AND STORAGE IMPLEMENTATION IN NAVAL STATION PEARL HARBOR
Pete Priester–Major, United States Marine Corps
Anthony Grusich–Lieutenant, United States Navy
Paul Tortora–Lieutenant, United States Navy
Master of Business Administration
Advisor: Nicholas Dew, Graduate School of Business and Public Policy
Co-Advisor: Eva Regnier, Defense Resources Management Institute

The purpose of this project is to examine the feasibility and cost effectiveness of liquid air energy storage and microgrid options to meet power demand aboard Naval Station Pearl Harbor. This infrastructure serves multiple Navy objectives, including providing standalone power support to endure emergency situations, providing pierside power for Navy vessels, enhancing the Navy's cost savings from the proposed utility scale West Loch solar PV project, and helping to meet the Navy's and Hawaii's renewable energy goals in accordance with Department of Defense mandates and

Navy-stated objectives for energy self-sufficiency and the goals of the Hawaiian Clean Energy Initiative. The results indicate that in grid-tied operation, a solar PV alone is the option with the highest financial net present value. Microturbines are the least-cost option to assure backup power in the event of a grid outage. The microgrid model in this study does not account for the possibility of using demand management to minimize power bills. Storage coupled with the proper control equipment and algorithms for demand management could improve its NPV by accounting for savings from arbitrage. This analysis will assist the Commander Navy Region Hawaii to determine specific actions to provide energy resiliency and self-sufficiency at Pearl Harbor. http://calhoun.nps.edu/handle/10945/45925

KEYWORDS: microgrid, microturbine, renewable energy, photovoltaic generation, electrical storage, energy storage

Electrical and Computer Engineering

INTERDIGITATED BACK-SURFACE-CONTACT SOLAR CELL MODELING USING SILVACO ATLAS

Shawn Green–Lieutenant, United States Navy
Master of Science in Electrical Engineering
Advisor: Sherif Michael, Department of Electrical and Computer Engineering
Second Reader: Matthew Porter, Department of Electrical and Computer Engineering

The Silvaco Atlas semiconductor modeling software was used to simulate an interdigitated back-surface contact solar cell. The cell is modeled after the silicon-based Sunpower Corporation A-300 solar cell, which contains a number of unique features that give it advantages over conventional solar cells. This simulation attempted to match as closely as possible the results measured by the National Renewable Energy Laboratory from the A-300 cell in order to validate the model. This model was then used to investigate the effects of making the A-300 thinner, which would permit its use in military solar blanket applications. A thin and flexible solar cell is ideal for this application due to its lighter weight, making it portable and flexible, which increases its ruggedness. The ability to simulate an interdigitated back-surface-contact cell also allows future work using computer algorithms to improve power output results as well as investigations into using materials other than silicon, which may further improve power output. http://calhoun.nps.edu/handle/10945/45861

KEYWORDS: solar cell, photovoltaic device, back surface contact, Silvaco Atlas, interdigitated, silicon

DESIGN, SIMULATION, AND PRELIMINARY TESTING OF A 20-AMPERE ENERGY MANAGEMENT SYSTEM

Matthew McCulley–Lieutenant Commander, United States Navy
Master of Science in Electrical Engineering
Advisor: Alexander L. Julian, Department of Electrical and Computer Engineering
Co-Advisor: Giovanna Oriti, Department of Electrical and Computer Engineering

The Department of the Navy is determined to find ways to increase the energy security of shore facilities. This is critical to ensure that facilities can meet fleet needs during a national crisis. An Energy Management System (EMS) using power electronics could be an important piece of this puzzle. In this thesis, a 20-ampere (A)-rated EMS module is designed and constructed that can be

used for demonstrations and field testing. The prototype is used to conduct preliminary testing of the EMS over-current trip circuit. This thesis discusses the analog and digital redesigns that are needed to overcome the electromagnetic interference from the switching currents of the power modules that leak into the control circuitry. Finally, a Simulink model is designed to simulate the expected output from the H-bridge portion of the EMS. This model is tested and verified using measurements from the actual EMS prototype in the laboratory. http://calhoun.nps.edu/handle/10945/45902

KEYWORDS: energy management system, microgrid, switching noise, electromagnetic interference

Mechanical Engineering

WIND EFFECTS ON SUN TRACKING SOLAR REFLECTING PANELS

Corwin Wagner–Lieutenant Commander, United States Navy
Master of Science in Mechanical Engineering
Advisor: Muguru Chandrasekhara, Department of Mechanical and Aerospace Engineering
Co-Advisor: Sanjeev Sathe, Department of Mechanical and Aerospace Engineering

Wind loads on sun-tracking solar reflector panels exposed to the atmospheric boundary layer were established through surface static pressure measurements to determine how wind affects them, specifically at the request of SPAWAR-Pacific, which has developed a custom design. A 1:8 scale model of a four-panel array was studied in the Naval Postgraduate School wind tunnel. Wind velocity, wind angle orientation, and individual panel positions, at which the highest pressure coefficient cases were anticipated, were varied. The pressure coefficients were measured by an array of Scanivalve pressure transducers with 16 pressure taps drilled into the top and bottom surfaces of each panel. Oil flow and smoke flow visualization techniques were performed to better understand the flow features that led to the greatest pressure coefficients. A parapet was included to observe the wind effects of various positions. Additionally, pressure measurements were observed using a rounded edge installed on the lead panel edges. This notion was to assist in not only minimizing wind loads, but also in determining a safe stow position of the array during high wind events. The measurements and the flow visualization studies both provided a cohesive and constructive picture of the flow. The windward panel was found to be subjected to the thrust of the wind loads in most cases, with a maximum recorded differential pressure coefficient of 3.25. However, when in combination with attaching the rounded edge to the windward panel and setting it negative five degrees, pressure coefficients were decreased by more than 70%. Parapets of the appropriate help also reduced the measured loads significantly. http://calhoun.nps.edu/handle/10945/45956

KEYWORDS: wind loads, wind effects, PV array, solar reflector panels.

Physics

POWER CONDITIONING FOR MEMS-BASED WASTE VIBRATIONAL ENERGY HARVESTER

Seyfullah Emen–Lieutenant Junior Grade, Turkish Navy
Master of Science in Physics
Advisor: Dragoslav Grbovic, Department of Physics
Co-Advisor: Sherif Michael, Department of Electrical and Computer Engineering

Increasing energy needs push industry to build more sustainable and efficient systems. One of the methods to achieve energy efficiency is to feed wasted energy generated by a system itself during operation back to the system. Vibrational energy is one of the most common ambient energy forms in mechanical systems and can be converted into electrical energy with the implementation of piezoelectric energy harvesters. What makes this possible is the piezoelectric effect that some crystals and ceramics with no inversion symmetry show. Piezoelectric materials generate a potential difference when a force is applied and deform under an electric field. Power electronics is used to turn this potential into a usable energy. The amount of power generated by a single piezoelectric energy harvester could be very low, but Microelectromechanical Systems (MEMS) technology makes it possible to have thousands of devices in a very small area. Previously, a MEMS-based piezoelectric harvester for military applications was designed, developed, and tested at NPS. In this thesis, methods to convert the AC voltage output of this device into a DC voltage were investigated to find an efficient method. Because of their higher power needs, multiple devices need to be connected to achieve required power levels for military applications. Microfabrication processes allow for building large number of such devices at the same time. This thesis also studies the possible connections for an array of devices. Connection geometry that will produce the maximum power output for a number of devices is proposed. http://calhoun.nps.edu/handle/10945/45848

KEYWORDS: MEMS, Waste Energy Harvesting, Piezoelectric, Power Conditioning, Piezoelectric Energy Harvester

Security Studies

LESSONS FROM FUKUSHIMA: RELOCATION AND RECOVERY FROM NUCLEAR CATASTROPHE

Gerilee Bennett–Deputy Director, National Disaster Recovery Planning Division, Federal Emergency Management Agency
Master of Arts in Security Studies (Homeland Security and Defense)
Advisor: Thomas Mackin, Center for Homeland Defense and Security
Co-Advisor: Frank Barrett, Graduate School of Business and Public Policy

The Fukushima nuclear plant meltdown offers an unusual opportunity to examine and learn from Japan's experience managing the forced, extended relocation of over 100,000 people. The objective of this study was to assess lessons the United States can incorporate into its disaster management plans from Japan's experience managing the relocation of communities due to the widespread contamination from the Fukushima Daiichi nuclear plant. Four years after the catastrophe, Fukushima Prefecture estimates 119,000 residents are still living in temporary accommodations while remediation work continues in 11 municipalities. This comparative analysis of the Fukushima case approached the challenge of planning for recovery after a nuclear/radiological disaster from the perspective of managers with limited radiation management expertise. It examined the progress of recovery in the first four years and the management practices related to the relocation and resettlement of the most contaminated Fukushima communities. The primary recommendation is that states and communities require guidance and tools to use both to prepare for major radiological incidents and as post-incident job aids for managing disaster recovery. Leaders and planners will be able to apply the study's detailed recommendations to enhance efforts to prepare for the intermediate and late-phase recovery from radiological disasters. https://calhoun.nps.edu/handle/10945/45815

KEYWORDS: disaster recovery, disaster planning, Fukushima, Great East Japan Earthquake, nuclear, radiological, disaster public information, stakeholder engagement, risk communication

Keywords: MEMS, waste energy harvesting, piezoelectric, power conditioning, piezoelectric energy harvester

SEPTEMBER 2015

Computer Science

FORMAL SPECIFICATIONS FOR AN ELECTRICAL POWER GRID SYSTEM STABILITY AND RELIABILITY

Jonathan Galinski–Captain, United States Marine Corps
Master of Science in Computer Science
Advisor: Doron Drusinsky, Department of Computer Science
Second Reader: Man-Tak Shing, Department of Computer Science

This thesis provides natural language requirements and associated formal specifications for an electric power grid. These specifications are the first step in using bounded constraint solving to detect early bleak states in an electric power grid system. We analyze several methods of software verification and validation including Theorem Proving, Model Checking, and Execution-based Model Checking before determining that Execution-based Model Checking is the most suitable for specifying properties of a power grid. The requirements and specifications are broken into four categories: undesirable events, downward trends, failure to recover, and undesirable fluctuations. All specifications are focused on system stability and reliability as indicated by system frequency and operating in a secure N-1 state. Specifications from three out of the four categories were tested to ensure they meet the spirit and letter of the natural language requirements while eliminating ambiguity inherent to natural languages. Finally, we show how a Hidden Markov Model can be used to perform run-time monitoring in the presence of hidden states, thereby enabling run-time monitoring of systems where monitored artifacts are not all perfectly visible. http://calhoun.nps.edu/handle/10945/47259

KEYWORDS: run-time monitoring, statechart assertions, formal specifications, electric power grid, hidden markov model

Electrical and Computer Engineering

DESIGN AND OPTIMIZATION OF COPPER INDIUM GALLIUM SELENIDE THIN FILM SOLAR CELLS

Daniel Katzman–Captain, United States Marine Corps
Master of Science in Electrical Engineering
Advisor: Sherif Michael, Department of Electrical and Computer Engineering
Second Reader: Matthew Porter, Department of Electrical and Computer Engineering

The objective of this thesis was to simulate a new way to create high efficiency Copper Indium Gallium Selenide (Cu(InGa)Se2) cells. This was accomplished by creating a model in Silvaco's technology computer aided design ATLAS program. A baseline model was tested to confirm functionality of the software, and a stepwise approach was used to include additional features. The first addition was the inclusion of a multi-layer absorber layer with graded Ga concentrations. This layer showed increased internal electric fields, which helped to increase the output of the cell. This was followed by the replacement of the traditional n-type CdS buffer layer with a n-type ZnO buffer layer. The ZnO buffer layer was found to have better band alignment than CdS and resulted in a

significant improvement in device performance. Finally, a top grid was included which reducedthe output of the cell as a result of shading. The final simulation resulted in a Cu(InGa)Se2 cell that operated at 21.14% efficiency, a 21.9% increase from the baseline cell. http://calhoun.nps.edu/handle/10945/47285

KEYWORDS: CIGS, efficiency, solar, SILVACO, ATLAS

FERRITE LOADED COILS FOR IMPROVED WIRELESS POWER TRANSFER EFFICIENCY

Seth Rosenberry–Lieutenant Commander, United States Navy
Master of Science in Electrical Engineering
Advisor: David Jenn, Department of Electrical and Computer Engineering
Second Reader: Roberto Cristi, Department of Electrical and Computer Engineering

Recharging the battery system on Navy Autonomous Underwater Vehicles requires physical electrical contact between the vehicle and a docking station specifically designed to accommodate only one particular hull size. Inductive power transfer using mutually coupled coils eliminates physical contact, which can lead to an electrical short in a seawater environment, and provides the flexibility needed to create a docking station that can accommodate numerous hull sizes. Unfortunately, the power-transfer efficiency between these coils in an undersea environment can be very poor due to the conductivity of seawater. To improve the power-transfer efficiency, the magnetic flux generated by the transmitting coil can be better concentrated through the receiving coil by careful geometric placement of ferrite materials. In this report, various ferrite configurations were evaluated using Computer Simulation Technology, and several high performance models were selected for construction and laboratory testing. The measured data collected in the laboratory are in good agreement with the simulation results, which indicate that the laboratory model and circuit closely adhered to the physical and electrical parameters of the simulation. This also underscores CST's usefulness for continued work in the field. http://calhoun.nps.edu/handle/10945/47323

KEYWORDS: wireless power transfer, inductive power transfer, autonomous underwater vehicle, mutually coupled coils, ferrite

MAXIMUM POWER POINT TRACKING OF A PHOTOVOLTAIC SYSTEM UTILIZING AN INTERLEAVED BOOST CONVERTER

James Topping–Major, United States Marine Corps
Master of Science in Electrical Engineering
Advisor: Giovanna Oriti, Department of Electrical and Computer Engineering
Co-Advisor: Alexander L. Julian, Department of Electrical and Computer Engineering

Over the last several years, the Department of Defense has focused on conserving energy in order to enhance its combat capabilities. Renewable energy technologies, such as wind, solar, biomass, and others, have been explored so that the military can reduce its reliance on fossil fuels and improve its operational range. One of the components to this effort is solar photovoltaic (PV) technology. The purpose of this thesis is to demonstrate the importance of using a maximum power point tracking (MPPT) algorithm to ensure that a PV system provides the most energy possible. Moreover, two different MPPT algorithms are presented in this thesis. An interleaved boost converter controls the flow of power to a load and a 24-volt source. Also, it regulates the PV panel's voltage and current so that the panel may operate at its maximum power point. A complete model of the solar panel, boost converter, and control algorithms was created in Simulink in order to validate the system in simulation. The control algorithms were implemented using a field-programmable gate array so that

the actual system could be tested and compared against the simulation. Experimental measurements validate the model and demonstrate that the MPPT algorithms perform as expected. http://calhoun.nps.edu/handle/10945/47339

KEYWORDS: solar, photovoltaic, maximum power point tracking, MPPT, interleaved boostconverter, Xilinx, field-programmable gate array, perturb and observe, incremental conductance

Operations Research

OPTIMAL SCHEDULING OF TIME-SHIFTABLE ELECTRIC LOADS IN EXPEDITIONARY POWER GRIDS

The following paper has been recognized as outstanding by its department.

John Sprague–Lieutenant Commander, United States Navy
Master of Science in Operations Research
Advisor: Emily Craparo, Department of Operations Research
Second Reader: Daniel Nussbaum, Department of Operations Research

Environmental control on the battlefield enhances readiness, reduces casualties, and protects the sensitive equipment upon which U.S. doctrine relies. Purchase and delivery of fuel necessary to provide this service was responsible for an estimated $1.4 billion in costs and 33 resupply convoy casualties per year at the peak of U.S. wars in Iraq and Afghanistan. It is well understood that the current semi-autonomous mode of environmental control unit (ECU) operation results in generators operating at low average loads—and low fuel efficiency— to accommodate periodic unmanaged spikes in peak load.We propose a mechanism to reduce costs through optimal prescriptive management of these ECUs. We exploit the fact that ECU operation is time-shiftable to develop a mixed-integer linear programming model that optimally schedules ECUs to eliminate unmanaged peak demand, reduce generator peak-to-average power ratios, and facilitate a persistent shift to higher fuel efficiency. Using sensitivity analysis, we quantitatively demonstrate how grid composition, temperature band tolerance, and energy storage capabilities contribute to fuel efficiency under this approach. http://calhoun.nps.edu/handle/10945/47332

KEYWORDS: expeditionary, energy, optimization, deferrable, fuel, mixed integer linear program

Space Systems

CONJUNCTION OF PHOTOVOLTAIC AND THERMOPHOTOVOLTAIC POWER PRODUCTION IN SPACECRAFT POWER SYSTEMS

Matthew Thomas–Lieutenant, United States Navy
Master of Science in Space Systems Operations
Advisor: Sherif Michael, Department of Electrical and Computer Engineering
Second Reader: Matthew Porter, Department of Electrical and Computer Engineering

This research examines the potential for the conjunction between photovoltaic (PV) and thermophotovoltaic (TPV) technologies for spacecraft power production. There is sufficient overlap between the sources of energy used for these devices and the function of the devices themselves that either PVs or TPVs could gain improvements in efficiency from the integration of the other type of device, or that a hybrid device could be developed. As a proof of concept, a GaAs PV cell and GaSb

TPV cell were modeled in a tandem design using Silvaco ATLAS, with varying PV cell substrate thicknesses, and simulated under the AM0 spectrum to determine the potential range of efficiency gains for a PV device integrated with a TPV device. The same design was then tested under a 2000 K blackbody spectrum—to approximate use in a radioisotope thermoelectric generator—to determine if similar efficiency gains could be seen for a TPV device integrated with a PV device. The possible gains with a PV-TPV design under AM0 are clear, potentially resulting in cells with a 30–34% overall efficiency. The possible gains for a PV-TPV device utilizing a blackbody spectrum are less clear, and would benefit from further design and investigation. http://calhoun.nps.edu/handle/10945/47338

KEYWORDS: photovoltaic, PV, thermophotovoltaic, TPV, gallium arsenide, GaAs, gallium antimonide, GaSb, radioisotope thermoelectric generator, RTG, blackbody spectrum, tandem cell, dual-junction, Silvaco ATLAS

Systems Engineering

ARCHITECTURE ANALYSIS OF WIRELESS POWER TRANSMISSION FOR LUNAR OUTPOSTS

William Reynolds–Captain, United States Air Force
Master of Science in Systems Engineering Management
Advisor: Charles Racoosin, Space Systems Academic Group
Second Reader: Robert Harney, Department of Systems Engineering

To continue scientific research on the moon, largely abandoned since the Apollo era, humanity must establish a permanent outpost. This research has narrowed the lunar base sites to the polar regions, as these sites offer the highest scientific value. The overarching problem is how to supply continuous power to lunar bases located at the poles. This study focuses on the feasibility and architectural analysis of wireless power transfer to lunar polar outposts. Two wireless power transfer methods, microwave and laser, were integrated into satellite constellations and the overall system architecture. The two architectures were modeled, analyzed, and evaluated to determine which method is more feasible. The results showed that while both the use of microwave and laser transmission were feasible, the microwave approach produced large transmitter and receiver antenna sizes, driving unreasonable cost. The laser transmission approach showed less end-to-end efficiency and therefore higher per-satellite cost but resulted in a lower total system cost and was the more feasible architecture. http://calhoun.nps.edu/handle/10945/47318

KEYWORDS: power beaming, wireless power transfer, lunar outposts, solar power satellites

DECEMBER 2015

Graduate School of Business and Public Policy

COST ANALYSIS OF A TRANSITION TO GREEN VEHICLE TECHNOLOGY FOR LIGHT DUTY FLEET VEHICLES IN PUBLIC WORKS DEPARTMENT–NAVAL SUPPORT ACTIVITY MONTEREY (PWD MONTEREY)

William I. Coffeen, IV–Lieutenant Commander, United States Navy
Paul G. DeVorse–Lieutenant Commander, United States Navy
Scott H. Margolis–Lieutenant, United States Navy
Master of Business Administration
Advisor: David R. Henderson, Graduate School of Business and Public Policy
Co-Advisor: Daniel A. Nussbaum, Department of Operations Research

The MBA Project is a detailed cost analysis of various mature green vehicle technologies that can be implemented by Public Works Department–Naval Support Activity Monterey (PWD Monterey) and its subordinate entities, with the intent of reducing both overall life-cycle vehicle costs and carbon emissions. The focus is on light-duty, non-tactical vehicles in use in the region. The cost analysis explores Plug-In Hybrid Electric Vehicles (PHEV), the infrastructure required to operate them, and the social cost of carbon emissions (SCC). Our model indicates that it is not economically beneficial to implement green vehicle technologies on a fleet-wide level for PWD Monterey. Although there are SCC benefits, and right-sizing fleet vehicles to suitable alternatives leads to savings, the increased cost of PHEVs and relatively large required infrastructure cost outpace the total benefits. http://calhoun.nps.edu/handle/10945/47924

KEYWORDS: plug-in, hybrid, electric, public works, energy, green vehicle, cost estimation, cost-benefit analysis, net present value

FACTORS THAT FACILITATE OR HINDER FUEL-SAVING INITIATIVES AND TECHNOLOGY

David Henton–Lieutenant Commander, United States Navy
Kurtis Noack–Lieutenant Commander, United States Navy
Master of Business Administration
Advisor: Kathryn Aten, Graduate School of Business and Public Policy
Co-Advisor: Anita Salem, Graduate School of Business and Public Policy

This report presents a case study analysis into the factors that facilitate or hinder the implementation of fuel-saving initiatives and technology implementation in commercial vehicle fleets. Recognizing the enduring success of FedEx Express in an industry that must utilize a fleet of vehicles to accomplish its mission, an exploration was conducted into how the company has pursued savings in fuel costs through best practices and new technologies. Encouraged by opportunities to optimize both new and existing company assets, FedEx sought both qualitative solutions in routing tactics and opportunities provided by new technology. FedEx leveraged the power of their people to make responsible energy use a corporate professional standard without compromising the core mission of on-time delivery. The ability to ingrain constructive changes into an everyday activity fostered belief in the changes and promoted the acceptance of technical solutions that supported organizational initiatives. This case study offers insight into how organizations can extract value by combining technology and existing corporate social elements. A key concept for success that was observed in

this FedEx case study was maintaining a keen awareness of corporate objectives while exerting control over the pace of any changes introduced. http://hdl.handle.net/10945/47959

KEYWORDS: telematics, fleet fuel use, technology implementation, and change management.

MOVEMENT OF FUEL ASHORE: STORAGE, CAPACITY, THROUGHPUT, AND DISTRIBUTION ANALYSIS

Michael Herendeen–Captain, United States Marine Corps
Master of Science in Management
Advisor: Chad Seagren, Department of Operations Research
Second Reader: Kenneth Doerr, Graduate School of Business and Public Policy

The Marine Corps' recent reemphasis on amphibious operations has identified a potential operational reach gap in the sustainment window of the Marine Expeditionary Brigade (MEB) in an undeveloped theater. This problem is defined by a limited capacity to move fuel ashore from tactical and sea-based assets, coupled with increasing rates of end-user consumption. In the absence of host-nation support, sustaining the MEB during operations ashore requires joint interoperability of several fuel distribution systems and methods of resupply. The success of the sea-based logistics network will depend on the use of a modern planning and forecasting approach. It is the aim of this study to understand the connection between the GCE's operational behavior and its fuel demand. This is accomplished through the use of the MAGTF Power and Energy Model to create a fuel usage data set. Subsequent regression analysis reveals key trends and provides insight into how operational decisions can result in marginal changes to fuel demand. Finally, this study examines the feasibility of fuel movement ashore using only the ship-to-shore connectors available to the MEB. http://hdl.handle.net/10945/47960

KEYWORDS: Marine Corps, fuel, energy, logistics, expeditionary, amphibious, and operational reach.

APPLYING RISK AND RESILIENCE METRICS TO ENERGY INVESTMENTS

Brendan Teague–Lieutenant, United States Navy
TJ Goss–Lieutenant, United States Navy
Mark Weiss–Lieutenant, United States Navy
Master of Business Administration
Advisor: Daniel Nussbaum, Department of Operations Research
Co-Advisor: Alan Howard, Global Public Policy Academic Group

The purpose of this research is to develop a more comprehensive energy investment decision model that includes intangible factors related to risk and resiliency. Additionally, this project evaluates the current Department of the Navy energy investment model and pinpoints how gaps and shortfalls lead to increased exposure to avoidable energy risk. The project selects the relevant risk and resiliency factors for inclusion, and then quantifies them as inputs for a new decision making model. The model developed for this project includes cost metrics and policy mandates that the current model considers and adds the intangible factors related to risk and resiliency. To validate the model, the Bloom Box Energy Server is evaluated under the status quo and then again under the new model, with risk and resiliency playing a larger role in the outcome. The results show that under the status quo, the Bloom Box is a poor energy investment; however, when evaluated under the new model, the Bloom Box is a more attractive investment due to the energy security and independence it provides. The different outcomes show that energy risk and resiliency factors affect energy decisions. This project then recommends follow-on research options to further develop and validate the model.
http://calhoun.nps.edu/handle/10945/47883

KEYWORDS: energy risk factors, energy resilience, renewable energy, energy security, energy independence, energy investment, energy model

DOWNSTREAM BENEFITS OF ENERGY MANAGEMENT SYSTEMS

Theodore J. Vermeychuk–Lieutenant Commander, United States Navy
Master of Business Administration
Advisor: Nick Dew, Graduate School of Business and Public Policy
Co-Advisor: Eva Regnier, Graduate School of Business and Public Policy

This report examines the downstream benefits of energy management systems (EMS) at Department of Defense (DOD) installations. The DOD has mandated thorough energy metering at shore installations, but EMSs are not widespread within the DOD. Four DOD installations with EMSs serve as individual case studies in a multiple-case study analysis. This report identifies three categories of downstream benefits associated with EMSs: addressing errors that cause energy waste, identifying wasteful buildings on an installation, and identifying valuable follow-on investments. Much of the value associated with EMSs is in analyzing the data provided, and future improvements in EMS data analysis will likely yield additional benefits. http://calhoun.nps.edu/handle/10945/47893

KEYWORDS: energy management systems, energy intensity, installation, downstream benefits, return on investment

Physics

CHARACTERIZATION OF PIEZOELECTRIC ENERGY HARVESTING MEMS

Ryan D. Johnson–Lieutenant Commander, United States Navy
Master of Science in Applied Physics
Advisor: Dragoslav Grbovic, Department of Physics
Co-Advisor: Fabio Alves, Department of Physics

Energy conservation and increased efficiency lie at the forefront of defense missions, capabilities, and costs. Expeditionary forces require energy efficient devices embarkable on naval, ground, and air assault vessels. Piezoelectric MEMS (microelectromechanical systems) devices can be used to convert energy— usually lost to mechanical vibrations—into usable electrical energy without adding significant weight or size to existing equipment. Previous work has analyzed materials and processes, and designed a piezoelectric energy harvesting device leading to its fabrication and characterization. This thesis experimentally tests the piezoelectric MEMS device and integrates the results into a refined model. The effects of Rayleigh damping and squeeze film damping are introduced to improve the connection between experimental data and a finite element model using COMSOL Multiphysics. This model exhibits good agreement with experimental results for resonant frequencies and output potential. From this model, the design can be optimized to resonate at 60 Hz. http://calhoun.nps.edu/handle/10945/47971

KEYWORDS: MEMS, piezoelectric energy harvester

DESIGN OF HIGH POWER FELS AND THE EFFECTS OF DIFFRACTION ON DETUNING IN AN FEL OSCILLATOR
Michael Jayson Price–Lieutenant, United States Navy
Master of Science in Applied Physics
Advisor: Joseph Blau, Department of Physics
Second Reader: Keith Cohn, Department of Physics

In experiments going back to the first free electron laser (FEL) oscillator at Stanford, the measured width of the desynchronism curve is often significantly greater than predicted by theory and two-dimensional (2D) simulations in (z; t). The results of new four-dimensional (4D) simulations in (x;y; z; t) show that this difference can be explained by the effects of diffraction. When the light is artificially constrained to remain in the cavity fundamental mode, 2D and 4D simulations give similar results, but when the light is allowed to self-consistently develop higher-order modes, the 4D simulations give different results that agree better with experiments. The results of new 4D simulations also show the effects of emittance versus electron beam energy and mirror shift versus mirror tilt on extraction. Analysis of these results examine the robustness of FEL designs. http://calhoun.nps.edu/handle/10945/47850

KEYWORDS: FEL, emittance, energy spread, mirror tilt, mirror shift

Security Studies

ENERGY CRISIS IN PAKISTAN
Malik Naseem Abbas–Lieutenant Colonel, Pakistan Army
Master of Arts in Security Studies (Combating Terrorism: Policy & Strategy)
Advisor: Robert Looney, Department of National Security Affairs
Co-Advisor: Siamak T. Naficy, Department of National Security Affairs

It is a universal phenomenon that the socio-economic progress of a state is significantly dependent upon the performance of the energy sector, as the energy sector drives the engine of growth and development in agricultural, industrial, and defense sectors, in addition to impacting domestic users. In Pakistan, the increasing gap between the demand for, and the supply of, energy has brought economic progress to a standstill. A number of industries have been closed due to this increasing gap, which is expected to grow even further. Despite huge indigenous potential and its geographical significance as a potential energy corridor between the Middle East and Central Asia, Pakistan's energy sector fails to secure its energy needs. The goal of this thesis is to evaluate why Pakistan's energy crisis is worsening day by day, and how the country can best secure its energy needs. http://calhoun.nps.edu/handle/10945/47900

KEYWORDS: energy crisis, energy security, gas pipelines, governance, coal, economy, resources, policies, oil and gas, renewable energy, tariffs, regional security

ENERGY SECURITY IN JORDAN
John Steiner–Captain, United States Air Force
Master of Arts in Security Studies (Middle East, South Asia, Sub-Saharan Africa)

Advisor: Robert Looney, Department of National Security Affairs
Co-Advisor: James Russell, Department of National Security Affairs

This thesis explores if the energy strategy of the Hashemite Kingdom of Jordan, as formulated and executed by the Ministry of Energy and Mineral Resources, will help the country achieve greater energy security. This work qualitatively analyzes the progress in each energy subsector—hydrocarbons, nuclear power, and renewables—on goals presented in the country's strategy and provides further analysis to determine each subsector's potential to play a greater role in future energy development. The primary conclusion is that the goals within Jordan's overarching energy strategy have not been realized, and, consequently, the strategy is not on track to provide energy security. This conclusion is based on three main findings. First, Jordan failed in meeting targets to diversify and exploit domestic hydrocarbon resources—being forced to rely on foreign heavy fuels and running a deficit to meet basic energy needs. Second, the kingdom's nuclear program has not kept up with development milestones and further nuclear progress is hampered by significant political and resource constraints. Third, the administration in Amman has been unsuccessful in fully capitalizing on the abundance of renewable energy resources readily available within Jordan's borders. http://hdl.handle.net/10945/47877

KEYWORDS: Hashemite Kingdom of Jordan, Jordan, energy security, energy strategy, hydrocarbons, nuclear energy, and renewable energy.

Systems Engineering

POWER MANAGEMENT SYSTEM DESIGN FOR SOLAR-POWERED UAS

Robert T. Fauci III–Lieutenant, United States Navy
Master of Science in Systems Engineering
Advisor: Alejandro Hernandez, Department of Systems Engineering
Co-Advisor: Kevin Jones, Department of Mechanical and Aerospace Engineering

Drone technology has catapulted to the forefront of military and private sector research. Of particular interest are unmanned aerial systems that are able to stay airborne for extended periods by absorbing energy from the environment. This requires extreme aerodynamic efficiency in order to minimize the power required to maintain flight, and a recognition that every sub-system in this system of systems must operate at optimal levels in order to achieve this nearly perpetual flight. A critical component of a drone is the electrical hardware that optimizes solar energy absorption and manages energy storage. In particular, weight-to-power consumption demands consideration as inefficiencies quickly equate to additional power requirements. While off-the-shelf components are available for many of the individual pieces, none of these parts is optimized with size and weight in mind. Therefore, the impetus of this thesis is to examine the power management system within a systems engineering framework. This study includes maximum power point tracking, battery management, energy storage and flux tracking by the batteries, propulsion, avionics and payload components. The results drove the design and development of a compact single circuit that optimally integrates these sub-systems into a lightweight module for particular mission sets. http://calhoun.nps.edu/handle/10945/47942

KEYWORDS: solar efficiency, maximum power point tracker, solar array, unmanned aerial system, power management

A METHODOLOGY TO ASSESS THE BENEFIT OF OPERATIONAL OR TACTIC ADJUSTMENTS TO REDUCE MARINE CORPS FUEL CONSUMPTION

Systems Engineering, Team E20
Master of Science in Systems Engineering and Master of Science in Engineering Systems
Advisor: Eugene P. Paulo, Department of Systems Engineering
Co-Advisor: Brigitte Kwinn, Department of Systems Engineering
Co-Advisor: Paul Beery, Department of Systems Engineering

The United States Marine Corps is too dependent on fossil fuel, which leaves logistics fuel support and supply lines vulnerable to attack, potentially degrading Marine Corps capabilities and ultimately putting Marines at risk. A need exists to identify doctrine, organization, training, materiel, leadership and education, personnel, and facilities (DOTMLPF) changes that provide a positive impact on energy efficiency while maintaining or improving operational effectiveness, essentially improving operational reach. Using the systems engineering process, key capabilities were identified from the Expeditionary Energy Office (E2O) stakeholders and used to develop a methodology to assess potential improvements to operational reach in the context of a Marine Expeditionary Unit (MEU) operation. At the heart of the methodology was a discrete event model developed to simulate the conditions of a close air support (CAS) operation and ground combat support (GCS) operation. Using a specific ship-to-shore vignette, factors were identified and a design of experiments (DOE) analysis was conducted to assess changes to doctrine, aircraft materiel solution, and environmental conditions on operational reach. This report: a) demonstrates the methodology developed, b) identifies the effects of the factors on extending the operational reach of a CAS and GCS operation, and c) recommends future efforts to continue research. http://hdl.handle.net/10945/47864

Keywords: systems engineering, model-based systems engineering, fuel consumption, close air support, ground combat support, operational effectiveness, DOTMLPF.

A HUMAN SYSTEMS INTEGRATION APPROACH TO ENERGY EFFICIENCY IN GROUND TRANSPORTATION

Keith R. Robison–Lieutenant, United States Navy
Master of Science in Systems Engineering
Advisor: Alejandro Hernandez, Department of Systems Engineering
Co-Advisor: Anita Salem, Graduate School of Business and Public Policy

This effort establishes the feasibility of implementing telematics systems into theUnited States Marine Corps' decision-making process in order to increase its operational reach and overall effectiveness. It is based around a qualitative case study evaluation of commercially implemented telematics. Telematics, as defined by Fleetmatics, is the integrated use of telecommunications combined with information and technology communication systems used to achieve improved operational capabilities while creating a more effective and efficient workforce. This research was done through numerous interviews with a variety of personnel who use telematics. The information is then partitioned and analyzed using a systems engineering framework utilizing a human systems integration methodology. This analysis acts as a framework to outline best practices in metering and monitoring. Once established, it is applied to the Marine Corps to determine a feasible way to

implement similar technologies on its ground vehicles. This study prescribes policies for the successful use of telematics systems in the Marine Corps that will make it a more fuel-efficient fighting force. As a result, the Marine Corps extends its operational reach, improves its warfighting capability, and reduces the risk to the warfighter. http://calhoun.nps.edu/handle/10945/47855

KEYWORDS: systems engineering, human systems integration, telematics, operational energy usage

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Operations Research

OTTER: AN OPTIMIZED TRANSIT TOOL AND EASY REFERENCE

Warren Korban Blackburn–Lieutenant Commander, United States Navy
Master of Science in Operations Research
Advisor: Emily Craparo, Department of Operations Research
Co-Advisor: Connor McLemore, Department of Operations Research
Second Reader: Daniel Nussbaum, Department of Operations Research

Fuel efficiency is a priority for the Chief of Naval Operations (CNO), as stated in the CNO's Position Report: 2014. While a number of fuel-saving measures have been implemented in recent years, the effects of operational transit speed on fuel consumption have not been adequately understood as a variable. Ships' commanding officers use fuel-usage curves to determine the most efficient propulsion-plant speed. Fuel efficiency is typically gauged by maintaining a consistent optimal speed. Often there are combinations of speeds that are more efficient than a constant speed. The transit fuel planner, developed in the Naval Postgraduate School's operations research department by Brown, Kline, Rosenthal, and Washburn in 2007, calculates speed combinations to achieve fuel savings for a given single ship. This thesis adds additional capacities based upon common principles. We provide an omnibus tool, the Optimized Transit Tool and Easy Reference (OTTER), with two complementary components: Dynamic OTTER and Static OTTER. Dynamic OTTER is a versatile, interactive transit-planning tool for any ship class that accommodates drill scheduling, a critical feature. The second tool, Static OTTER, is a generic, optimal solution to individual ship transit-speed combinations, in the form of a printable reference sheet that can be used independently. These products are being implemented by United States Navy surface ships and will yield significant fuel savings, equating to additional time on station. http://calhoun.nps.edu/handle/10945/48585

KEYWORDS: OTTER, fuel optimization, transit fuel planner, fuel savings, fuel consumption, replenishment at sea planner surface fleet, surface action group planner

Security Studies

OIL AS A WEAPON OF THE 21ST CENTURY: ENERGY SECURITY AND THE U.S. PIVOT TO ASIA-PACIFIC

Jay C. English–Lieutenant, United States Navy
Master of Arts in Security Studies (Middle East, South Asia, Sub-Saharan Africa)

Advisor: James Russell, Department of National Security Affairs
Second Reader: Daniel Moran, Department of National Security Affairs

This thesis examines the U.S. pivot to Asia to determine whether energy security issues are likely to complicate relations and/or lead to friction between the United States and China in the twenty-first century. Drawing on case studies in which energy issues directly and indirectly drive states' decisions to use military force to secure access to energy resources, or leverage access to resources as a means of coercive diplomacy, this research projects how similar scenarios may develop in the twenty-first century. The analysis also supports the notion that mutual interests in access to Middle Eastern energy resources and centrality of the Sea Lanes of Communication (SLOCs) in its transport could result in cooperative security arrangements in the absence of preferential access to any country. Conflict could potentially result from territorial disputes involving U.S. collective defense treaty allies. For this reason, it is recommended that the United States pursue a diplomatic solution to territorial disputes and avoid policies that limit China's access to the SLOCs. http://calhoun.nps.edu/handle/10945/48515

KEYWORDS: China, PACOM, Asia Pacific, Central Asia, National Security Strategy, Energy Security, Trans Pacific Partnership, Pivot to the Pacific, Strait of Malacca, Strait of Hormuz.

ANALYZING THE RATIONALES BEHIND RUSSIA'S INTERVENTION IN UKRAINE

Kevin T. Thomas–Major, United States Air Force
Master of Arts in Security Studies (Europe and Eurasia)
Advisor: David S. Yost, Department of National Security Affairs
Second Reader: Mikhail Tsypkin, Department of National Security Affairs

This thesis examines the rationales behind Russian President Vladimir Putin's decision to intervene in Ukraine through the lenses of neoclassical realism and prospect theory. The risk-acceptant decision to employ hybrid warfare in Crimea was fundamentally due to Putin's loss aversion. Since Putin frames his political decision-making reference point in the realm of losses, his decision sought to prevent the imminent losses of Ukraine's Russian-oriented government, Russia's influence in Ukraine, and Putin's own political power at home. It also sought to somewhat recover from the catastrophic loss of the Soviet Union's territorial possessions, population, and status. Putin exploited Western leaders' naiveté and vulnerabilities to prepare a geopolitical landscape wherein Russia could act without incurring excessive costs. Emboldened by Russia's large financial reserves and backed by Russia's seemingly irrational threats of cutting off essential European gas supplies and launching nuclear attacks, Putin correctly anticipated a limited economic sanctions response and a negligible military response from the West. Putin's decision furthered Russia's interests by acquiring Crimea, the strategically indispensable port of Sevastopol, and vast Black Sea region resources. Such action also thwarted the expansion of Western institutions in Ukraine and incited fervent Russian ethno-nationalism, boosting Putin's domestic approval ratings to an unprecedented level. http://calhoun.nps.edu/handle/10945/48483

KEYWORDS: neoclassical realism, prospect theory, rationality, hybrid warfare, Budapest Memorandum, Crimea annexation, EU association agreement, NATO expansion, Euromaidan, Yanukovych, post-Soviet identity, spheres of interest, Russo-Georgian war, Black Sea Fleet, oil and gas resources, Putin, Russian nationalism, domestic politics, color revolutions, Gazprom, gas wars, European gas dependence, nuclear messaging, foreign reserves, economic sanctions