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A Bibliography of NPS Space Systems Related Student Research, 2013-2022

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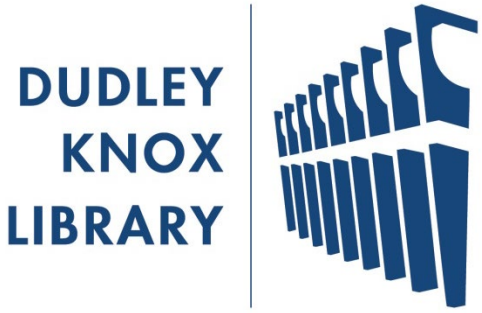

NAVAL POSTGRADUATE SCHOOL
MONTEREY, CALIFORNIA

A BIBLIOGRAPHY OF NPS SPACE SYSTEMS RELATED STUDENT RESEARCH, 2013-2022

Compiled by

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ABSTRACT

This is a bibliography of NPS student research (dissertations and theses) related to space systems topics. Coverage is for 2013-2022 and only includes publicly released materials. The primary degree areas covered (but not limited to) were:

PhD – Astronautical Engineering

MS – Astronautical Engineering
MS – Engineering Science
MS – Space Systems Operations
MS - Systems Engineering Management
MS - Systems Technology (Command, Control, and Communications)

There are also a few theses generally related to space from the political science/social science degree programs that have not been included. Those theses as well as the space systems-related research done by NPS faculty can be found by searching *Calhoun*, the NPS digital repository. https://calhoun.nps.edu/

Additional collections in *Calhoun* that might also be of interest include:

- Space Systems Academic Group publications
  https://calhoun.nps.edu/handle/10945/30320
- Space Systems technical reports
  https://calhoun.nps.edu/handle/10945/45693
- Spacecraft Reseach and Design Center Laboratories
  https://calhoun.nps.edu/handle/10945/35406
- Spacecraft Reseach and Design Center
  https://calhoun.nps.edu/handle/10945/35407

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PhD DISSERTATIONS

King, Jeffery T. **"A New Approach for Optimizing Image Collection from Space."** PhD diss. - Astronautical Engineering, Naval Postgraduate School, 2014.
https://hdl.handle.net/10945/49613
Abstract: The capability of space-based sensors to collect images is directly related to the agility of the sensor. Increasing the sensor agility can be accomplished using optimal control; however, planning for the increased performance is required in order to increase the overall collection capability of a system. This dissertation demonstrates how optimal control yields a higher agility for a given spacecraft system, and presents a new and simple method to estimate the performance increase. New targeting equations are developed that define the sensor attitude, rate and acceleration required to collect a moving target. Operational maneuvers are defined and generated using optimal control. Finally, a new formulation for the time-varying image collection planning problem is presented by combining graph theory with optimal control into a hybrid optimal control architecture.

Lan, Wenschel D. **"Development of a low-Cost Method for Whole-Spacecraft Isolation of Small Satellites."** PhD diss. – Astronautical Engineering, Naval Postgraduate School, 2015.
https://hdl.handle.net/10945/47804
Abstract: Force-limited vibration testing (FLVT) is effective in reducing the low-frequency vibration test environment for CubeSats on the Naval Postgraduate School CubeSat Launcher (NPSCuL); however, the CubeSats are still subjected to high-frequency amplifications above 500 Hz from the NPSCuL structure. The excessive, high-frequency vibration has caused test failures and forces CubeSat developers to focus more on surviving environmental testing instead of developing state-of-the-art technology. Whole-spacecraft isolation systems are often used to reduce these amplifications, but they currently exist only for large spacecraft and are too expensive to adapt for small satellites. These limitations motivated the combined use of FLVT and commercial-off-the-shelf (COTS) isolators on NPSCuL as a novel, practical, and low-cost method to reduce vibration levels for small satellites. This method significantly reduces the high-frequency amplification by up to 97%; the root-mean-square acceleration (GRMS) over the entire test frequency range drops by up to 78%. These results should allow more sensitive and complex payloads to gain access to space on future NPSCuL missions and demonstrate how a worst-case environment on a small satellite can be improved. Implementing low-cost, COTS isolators on other small satellites and CubeSat launch applications could be useful as well.

Magallanes, Lara C. **"Unscented Guidance for Point-to-Point Reaction Wheel Maneuvers."** PhD diss. - Astronautical Engineering, Naval Postgraduate School, 2022.
https://hdl.handle.net/10945/71501
Abstract: Attitude control system failures are often mission ending even when the mission payload remains operational. In this dissertation, the concept of unscented guidance is applied to reorient a reaction wheel satellite in the absence of feedback from star trackers or an inertial measurement unit (IMU). It is shown that an open-loop maneuver, properly designed using optimal control theory, can be used to achieve terminal attitude errors that are comparable with closed-loop control in the presence of uncertainty in the satellite inertia tensor. Typically, coarse closed-loop control is used to achieve < 1 degree pointing accuracy before more accurate pointing is done using fine guidance sensors to close the loop for science acquisition. It is shown that reaction wheel maneuvers designed using unscented guidance can also achieve sub-degree pointing accuracy of the spacecraft, making control hand-off to a functioning fine pointing control mode possible. The approach presented here enables large angle attitude control to be recovered so that mission operations may be continued despite IMU or star tracker failures.

McGrath, Christopher B. **"Unscented Sampling Techniques for Evolutionary Computation with Applications to Astrodynamic Optimization."** PhD diss. - Astronautical Engineering, Naval Postgraduate School, 2016.
https://hdl.handle.net/10945/50592
Abstract: This dissertation investigates several innovative approaches to evolutionary optimization that are relevant to numerous applications in astronautical engineering. The challenges and shortfalls associated with evolutionary algorithms are translated into three overarching goals that directly motivate the research and innovations of this dissertation. The first goal is to investigate and employ techniques that enable evolutionary algorithms to effectively handle constraints in a way that allows for feasible solutions to constrained optimization problems. The second goal is to improve computation times and efficiencies associated with evolutionary algorithms. The last goal is to enhance the evolutionary algorithm's robustness and ability to consistently find accurate solutions within a finite number of iterations. Novel techniques involving the application of unscented sampling, parallel computation, and various forms of exact penalty functions are developed and applied to both genetic algorithms and evolution strategies to achieve these goals. The results of this research offer a promising new set of modified evolutionary algorithms that outperform state-of-the-art techniques on a number of challenging multimodal optimization problems. In addition, these new methods are shown to be very effective in solving a minimum-propellant lunar lander optimal control problem, representing a class of problems that are historically difficult to solve using evolutionary algorithms.

Minelli, Giovanni. **"Resource-Constrained Autonomous Operations of Satellite Constellations and Ground Station Networks."** PhD diss. - Astronautical Engineering, Naval Postgraduate School, 2018. https://hdl.handle.net/10945/60435
Abstracts: To address the growing population of small satellite constellations that rely on distributed ground station networks, a dynamic optimization problem is formulated and solved. Specifically, this dissertation addresses the problem formulation, algorithm implementation, and experimental techniques developed to optimally slew ground-based antennas between multiple satellites that are simultaneously in view of one or more earth stations. The problem is solved using DIDO, a MATLAB optimal control solver, to produce deconflicted ground antenna slew trajectories. The deconfliction parameters include space-to-ground link budgets, mission priority, asset availability, and onboard health. Traditional methods employ heuristics to generate a subset of available targets and a separate process to check feasibility of the solution. The method described in this dissertation deterministically solves the problem in a single step. The approach is experimentally validated and tested using a small constellation of low-Earth-orbiting CubeSats operated by the Small Satellite Laboratory at the Naval Postgraduate School, using the Mobile CubeSat Command and Control (MC3) ground station network.

Zagaris, Costantinos. **"Autonomous Spacecraft Rendezvous with a Tumbling Object: Applied Reachability Analysis and Guidance and Control Strategies."** PhD diss. - Astronautical Engineering, Naval Postgraduate School, 2018.
https://hdl.handle.net/10945/60364
Abstract: Rendezvous and proximity operations are an essential component of both military and commercial space missions and are rising in complexity. This dissertation presents an applied reachability analysis and develops a computationally feasible autonomous guidance algorithm for the purpose of spacecraft rendezvous and proximity maneuvers around a tumbling object. Recent advancements enable the use of more sophisticated, computation-based algorithms, instead of traditional control methods. These algorithms are desirable for autonomous applications due to their ability to optimize performance and explicitly handle constraints (e.g., safety, control limits). In an autonomous setting, however, some important questions must be answered before an algorithm implementation can be realized. First, the feasibility of a maneuver is addressed by analyzing the fundamental spacecraft relative dynamics. Particularly, a set of initial relative states is computed and visualized from which the

desired rendezvous state can be reached (i.e., backward reachability analysis). Second, with the knowledge that a maneuver is feasible, the Model Predictive Control (MPC) framework is utilized to design a stabilizing feedback control law that optimizes performance and incorporates constraints such as control saturation limits and collision avoidance. The MPC algorithm offers a computationally efficient guidance strategy that could potentially be implemented in real-time on-board a spacecraft.

Zappulla, II, Richard Salvatore. **"Experimental Evaluation Methodology for Spacecraft Proximity Maneuvers in a Dynamic Environment."** PhD diss. - Astronautical Engineering, Naval Postgraduate School, 2017.
https://hdl.handle.net/10945/55567
Abstract: In an effort to pursue advanced space missions, improved onboard trajectory optimization and path-planning capabilities are necessary. Regardless of the mission, the paramount requirement for any candidate guidance-and-control method is the ability to react in real time to a dynamic environment, followed by fuel efficiency. Ground-based kinodynamic test beds are critical in developing, testing, and verifying these requirements. The NPS POSEIDYN test bed is introduced here as a state-of-the-art (SOTA) dynamic, hardware-in-the-loop test bed. Key improvements to the software architecture, enabling the development of multi-rate guidance, navigation, and control (GNC) algorithms, are presented in addition to a detailed system characterization. To aid in the experimental evaluation of GNC algorithms, a Standard Test Framework is proposed in addition to a new guidance comparison metric previously missing in the literature, which simultaneously captures the computational complexity and algorithm performance. Guidance and control methods representing the SOTA are experimentally evaluated and compared against a proposed rapidly exploring random tree-based guidance method using the proposed test framework and the comparison metric.

THESES

2022

Bonitz, Alexandria M. **"Investigation of Thermophotovoltaic Cell Designs for Use in Space Power Systems."** Master's thesis - Astronautical Engineering, Naval Postgraduate School, 2022. https://hdl.handle.net/10945/71046

Abstract: As technology and spacecraft design advance, the demand for power is ever more prevalent. Photovoltaic cells continue to be the industry standard for space power, and their efficiencies have progressed significantly. However, as spacecraft become more exquisite, modest solar arrays are scaling into massive booms, and time spent in eclipse is becoming increasingly problematic. Tuning photovoltaic cells to the infrared region, coupled with a thermal source, removes the requirement for sunlight and allows the spacecraft to generate electricity even in complete eclipse. Thermophotovoltaic (TPV) cells also allow a spacecraft to operate at great distances from the sun so long as a heat source is present. This thesis explores the possibility of incorporating TPVs coupled with nuclear power systems into spacecraft design for future Earth-bound and interplanetary missions.

Bonitz, Dylan A. **"Using Reinforcement Learning to Spoof a Monitored Kalman Filter."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2022. https://hdl.handle.net/10945/70634

Abstract: Modern hardware systems rely on state estimators such as Kalman filters to monitor key variables for feedback and performance monitoring. The performance of the hardware system can be monitored using a chi-squared fault detection test. Previous work has shown that Kalman filters are susceptible to false data injection attacks. In a false data injection attack, intentional noise and/or bias is added to sensor measurement data to mislead a Kalman filter in a way that goes undetected by the chi-squared test. This thesis proposes a method to deceive a Kalman filter where the attack data is generated using reinforcement learning. It is shown that reinforcement learning can be used to train an agent to manipulate the output of a Kalman filter via false data injection and without being detected by the chi-squared test. This result shows that machine learning can be used to successfully perform a cyber-physical attack by an actor who does not need to have in-depth knowledge and understanding of mathematics governing the operation of the target system. This result has significant real-world impact as modern smart power grids, aircraft, car, and spacecraft control systems are all cyber-physical systems that rely on trustworthy sensor data to function safely and reliably. A machine learning derived false data injection attack against any of these systems could lead to an undetected and potentially catastrophic failure.

Bourdow, Steven P. **"Multilateral Deterrence Formation and Future US Space Security Challenges."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2022. https://hdl.handle.net/10945/70635

Abstract: An increase in the number of satellites from commercial and military actors in the future will cause space to become more congested and contested. The increase in actors raises the question of how the United States could conduct space deterrence with proliferated space operations. The significance behind this is that the proliferation of satellites will impact the stability and security of space, creating more orbital debris and opportunities for adversary activities. Stability and security are characteristics that the United States deems critical for the future, as outlined in the 2020 National Defense Space Strategy. The United States' new challenge in space raises the importance of a flexible deterrence strategy. Options the United States could exercise include space weapons, allied cooperation, or legal methods, such as norms, codes of conduct, or treaties. Electronic warfare techniques such as jamming would be the best approach for flexible deterrence with space weapons to minimize orbital debris and conflict escalation. Multinational space networks would provide flexible approaches to deterrence in offensive or defensive constellations, while strengthening relationships between

partners. An increase in the awareness and transparency surrounding space behavior could result in better monitoring of inappropriate behavior and facilitate the new norms, codes of conduct, or treaties on responsible behavior, leading to a more secure and more stable space domain.

Laird, Brittany L. **"A Comprehensive Review of Internet of Things Waveforms for a DOD Low Earth Orbit CubeSat Mesh Network."** Master's thesis - Network Operations and Technology, Naval Postgraduate School, 2022.
https://hdl.handle.net/10945/71494
Abstract: The Department of Defense (DOD) requires the military to provide command and control during missions in locations where terrestrial communications infrastructure is unreliable or unavailable, which results in a high reliance on satellite communications (SATCOM). This is problematic because they use and consume more digital data in the operational environment. The DOD has several forms of data capable of meeting Internet of Things (IoT) transmission parameters that could be diversified onto an IoT network. This research assesses the potential for an IoT satellite constellation in Low Earth Orbit to provide an alternative, space-based communication platform to military units while offering increased overall SATCOM capacity and resiliency. This research explores alternative IoT waveforms and compatible transceivers in place of LoRaWAN for the NPS CENETIX Ortbial-1 CubeSat. The study uses a descriptive comparative research approach to simultaneously assess several variables. Five alternative waveforms—Sigfox, NB-IoT, LTE-M, Wi-sun, and Ingenu—are evaluated. NB-IoT, LTE-M, and Ingenu meet the threshold to be feasible alternatives to replace the LoRaWAN waveform in the Orbital-1 CubeSat. Six potential IoT transceivers are assessed as replacements. Two transceivers for the NB-IoT and LTE-M IoT waveforms and one transceiver from U-blox for the Ingenu waveform are assessed as compliant.

Loh, Wee Seng. **"Integration of LEDs as an Alternative Communication System for CubeSats."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2022.
https://hdl.handle.net/10945/71015
Abstract: The recent reduction in launch costs coupled with lower development costs has lowered the barrier of entry for satellite development and deployment, resulting in increasing numbers of satellites launched for civil, commercial, and educational institutions in the past decade. CubeSats are often manifested as secondary payloads onboard launch vehicles and are often deployed into the same orbit over a short time period. It has become difficult or impossible to immediately distinguish and track a specific satellite with traditional tracking methods using their onboard radio frequency (RF) communication systems. This thesis focuses on using light emitting diodes (LED) installed on a CubeSat to achieve tracking of the CubeSat in low-earth orbit (LEO) shortly after deployment and to that then utilize the LED payload to transmit the operating status or operational data to the ground stations.

Mathies, Max S. **"Analysis of Ideal Maneuvers for Mission Extension Vehicle."** Master's thesis - Astronautical Engineering, Naval Postgraduate School, 2022.
https://hdl.handle.net/10945/71506
Abstract: Finding optimal maneuvers between spacecraft is computationally demanding. Targeting many spacecraft successively requires more computational power than commercially available. This thesis tested algorithms looking to reduce this computational burden. Algorithms claiming optimal two-impulse rendezvous solutions between any two arbitrary orbits were coded and compared through minimum delta-vs (fuel) and computational times. Orbit characteristics were varied across a multitude of scenarios to represent many possible applications. Assorted considerations were discussed, which provided a framework for designing multi-client on-orbit servicing missions.

Quah, Yi Han Edwin. **"Small States in Space: Crafting a Strategy for Singapore."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2022.
https://hdl.handle.net/10945/71025
Abstract: Many nascent space powers have initiated strategic assessments and announced policy objectives to integrate space activities to serve their national interests. This thesis seeks to study: How should Singapore, a small state with limited capacities (e.g., geographical size, population, and resources), develop near-term policy objectives that best draw on its competitive advantages? This provides clarity to Singapore's progress as an emerging spacefaring nation, in response to emerging global trends in space and in leveraging space in meeting its national interests. To draw meaningful comparisons and lessons, this thesis examines the key policies, strategies, and programs as well as the objectives and priorities driving the sectoral developments of two trailblazing small states (the United Arab Emirates and Luxembourg). This thesis presents policy recommendations for Singapore to best capitalize on its competitive strengths as it progresses as an emerging spacefaring nation. Recommendations include institutionalizing national authority and space act, increased participation in bilateral and multilateral space cooperation and diplomacy, dedicating budget to the application of space security, and nurturing space ecosystem and talent pipeline.

Siew, Jun Jie. **"Deblurring of Optically Aberrated Satellite Imagery with Deep Learning (UNET)."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2022.
https://hdl.handle.net/10945/71034
Abstracat: Satellite imaging performance can degrade due to optical aberrations. To maximize a satellite's imaging output over its useful lifespan, deep learning presents a cost-effective alternative to traditional adaptive optics for deblurring satellite images. This is because deep learning is essentially a post-processing technique that relies on algorithms and a large dataset. This research focuses on applying deep learning algorithms based on the UNET Convolutional Neural Network, which is widely used in the bio-medical imaging field, to deblur optically aberrated satellite imagery. The XVIEW dataset, which is composed of images taken by the Worldview-3 satellite, is used. The XVIEW images are then simulated with optical aberrations (defocus and spherical) using Zernike polynomials. The blurred images are subsequently deblurred with UNET and UNET variants (UNET++ and UNET3+) before final performance evaluation with various image quality metrics. The results showed that (1) UNET algorithms can effectively deblur optically aberrated satellite images, and (2) UNET3+ modified with additional convolutional layers (deep-UNET3+) provided the best deblurring performance. Based on the positive results, this thesis recommends that the UNET algorithm be applied on actual field cases of optically aberrated satellite imagery and be further developed to perform better even on super-resolution applications.

Stephens, Bradley R. **"Design of a Parallel Educational Satellite Ground Station."** Master's thesis - Astronautical Engineering, Naval Postgraduate School, 2022.
https://hdl.handle.net/10945/70764
Abstract: The Mobile CubeSat Command and Control (MC3) ground station network provides communications infrastructure for small satellites developed by U.S. government organizations, contractors, and educational institutions. As the network has matured, so too have the cybersecurity requirements that govern its operations. By implementing tight configuration constraints on software, hardware, and networking, ground stations are unable to utilize the equipment outside standard operations. This poses a particular problem for educational institutions that routinely involve such equipment in their curricula for hands-on instruction and research. This research effort focuses on design, implementation, and testing of a parallel ground station to MC3 that allows educational institutions the freedom to innovate and perform research. The parallel station will share the MC3 antenna, the most valuable component of the ground station, but provide a separate rack of equipment that functions as a separate ground station. This research applies directly to those institutions that are currently members of the MC3 system. Currently, the Naval Postgraduate School, the United States Coast Guard Academy, and the United States Naval Academy have expressed interest in a parallel ground station. The resulting approach benefits these educational institutions by

removing barriers of development and increasing instructional impact in the ever-competitive worldwide aerospace industry.

Stuffle, Nathan D. **"Modification of Commercial Rocket Motors for Tactical Applications."** Master's thesis - Space Systems Operations & Astronautical Engineering, Naval Postgraduate School, 2022.
https://hdl.handle.net/10945/70766
Abstract: Several design modifications to commercial off-the-shelf solid rocket motors have been evaluated in support of the Naval Postgraduate School tactical rapid-response payload delivery vehicle. The modifications include a novel head-end ignition system and a tailorable nozzle end cap designed to provide reliable at-altitude ignition by improving the transient behavior of the initial combustion chamber pressure rise. The nozzle cap also provides the additional benefit of extending the shelf life of the propellant by creating an environmental seal to prevent ambient humidity from affecting the propellant. A preliminary design of a blast tube was proposed to explore how the motor exhaust could be channeled through a smaller-diameter tube before reaching the nozzle throat, thereby accommodating the volume requirements of aft fin control servos without sacrificing the overall rocket diameter or precluding use of larger-diameter rocket motors. Implementation of a blast tube also resulted in a favorable shift of the center of gravity of the rocket, which preserved and enhanced control authority during simulated fly-outs. All of the modifications were designed to be directly interchangeable with the OEM hardware to minimize the cost of implementing the new capabilities. Both the head-end ignition and nozzle enclosure systems were successfully demonstrated during flight testing, and a design process for the future implementation of a blast tube was proposed.

Villalpando, Leandra. **"Mobile CubeSat Command and Control Ground Station Architecture for Free-Space Optical Communication Receiver."** Master's thesis - Systems Engineering Management, Naval Postgraduate School, 2022.
https://hdl.handle.net/10945/71101
Abstract: The United States military continues to encourage the need for robust satellite communications in order to successfully execute defense missions. CubeSats are a smaller-scale spacecraft, initially utilized to expand educational opportunities in the field of aerospace and satellite communications. This research explores both existing and potential ground station architecture options for integration of free-space optical communication downlinks from CubeSats. Future experimentation plans will focus on the application of this capability in more diverse environments to include expanded ground architecture opportunities. Systems engineering design and architecture methods are useful in understanding the current hardware and software options and limitations for future expansion opportunities. By considering a comparable planning approach, alternatives for architecture development can be organized to aid in the identification of control factors for sub-system and ground communication interfaces. As a well-established CubeSat communications system, the existing Mobile CubeSat Command and Control (MC3) architecture serves as an excellent candidate for experimental integration and eventual considerations for a planned proof of concept.

2021

Arrigo, Grant P. **"Enhancing Naval Operations through Space Cooperation: The Role of Allies."** Master's thesis - Strategy (Space Operations), Naval Postgraduate School, 2021.
https://hdl.handle.net/10945/68292
Abstract: Since 1957, space has been a significant domain of great power competition, generating soft power and providing pronounced military benefits. As the United States enters an era of renewed great power competition with peer adversaries, the U.S. Navy, operating as a forward presence, faces increased challenges from Russia and China. This thesis investigates possible allied space coalition structures and how space cooperation can be leveraged as a force multiplier to enhance naval operations. Two case studies are featured as a means of evaluating current U.S. allies, their space capabilities, policies, and histories. Germany, France, and the UK are examined in the context of challenges from Russia in the Mediterranean and Arctic, and Japan, Australia, and South Korea are considered relative to the operational challenges in the South China Sea and a Taiwan contingency resulting from the rise of China. The military space programs of Europe are found to be much more developed and interconnected than the more nascent Indo-Pacific military space programs, which remain separated as a result of historical tensions and Cold War–era bilateral cooperation structures. Ultimately, this thesis determines that a U.S.-led space coalition should break from past bilateral or regional alliance structures in favor of a global space coalition to best leverage the benefits of burden sharing, deterrence, mission assurance, and increased capacity to support global maritime operations.

Beemer, Heidi D. **"Launch Parameters of an Ice Payload Traveling via Lunar Electromagnetic Launcher to the Lunar Gateway."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2021.
https://hdl.handle.net/10945/67105
Abstract: This paper investigated one possible solution for procuring propellent needed for future space exploration missions. This study examined the feasibility of using an electromagnetic launcher (EML) to transport raw materials used in propellent production from the lunar south pole to NASA's Lunar Gateway. This proposed space station, located in a lunar near-rectilinear halo orbit (NRHO), is a critical part of NASA's Artemis program. Cheaply and efficiently sourcing lunar hydrogen from surface ice to the station would benefit the program's success and future exploration of the solar system. This research investigated the launch requirements for a lunar EML payload. AGI Inc.'s Systems Tool Kit (STK) was used to calculate the required launch azimuth, elevation, magnitude, epoch, and trip duration needed to intercept the Gateway. The model evaluated the payload and the Gateway's radial, cross-track, and in-track positions and rates to determine their relative positions and velocities at rendezvous. Conclusions from this research demonstrated that it is feasible to conduct a single launch from the lunar south pole and target any point along the Gateway's orbit with variable launch conditions. Evidence supporting our hypothesis is presented, showing it may not be possible to match the space station's state vector at rendezvous. The payload will require an additional thrust capability, suggestions for which were also explored in this paper.

Claybaugh, Allyson A. **"Testing and Integration of CubeSat X-Band Software Defined Radio with Mobile CubeSat Command and Control (MC3) Ground Station."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2021.
https://hdl.handle.net/10945/67686
Abstract: A proven CubeSat form factor is leading to increasingly ambitious payloads and mission requirements, resulting in more data products and the need for higher space-to-ground transmission rates. This thesis contributes to the Naval Postgraduate School (NPS) CubeSat project and Mobile CubeSat Command and Control (MC3) initiative to increase network capacity through X-band downlinks. The Space Systems Academic Group at NPS is developing and fielding a 6U CubeSat with an X-band software-defined radio (SDR) payload, constructed using commercial-off-the-shelf hardware and operated via the MC3 ground station

network. The objective of this thesis research was verification of end-to-end compatibility between the X-band SDR payload and MC3 ground station receivers. Research, testing, and analysis determined radio frequency signal parameters and communications standards that enable transmission of data from the X-band SDR payload to the AMERGINT satTRAC SDR and Kratos quantumRadio SDR receivers. Simulation (through MathWorks Simulink models) and interoperability testing were conducted. Research culminated in demonstration of a successful baseband link from payload SDR hardware to both ground station receivers, with a QPSK-modulated, PN11 data transmission. Further functional and environmental testing will ensure the X-band SDR payload can effectively communicate on-orbit with the MC3 network.

Decker, Kyle W. **"System Design and Integration of a Rapid Response Payload Delivery Vehicle Using Commercial Off-the-Shelf Components."** Master's thesis - Astronautical Engineering, Naval Postgraduate School, 2021.
https://hdl.handle.net/10945/68707.
Abstract: This study involved the integration and implementation of multiple commercial off-the-shelf components into a rapid response payload delivery vehicle powered by a solid rocket motor. This work was motivated by the need to establish a proportional response to combat the presence of low-cost drone swarm technologies. Previous work was leveraged including flight data, system designs, and flight models to obtain the first objective of implementing a Raspberry Pi microprocessor, increasing the control loop response from 30 to 100Hz and improving the overall data acquisition attained from each flight. A proportional-derivative controller was then designed to successfully provide roll stabilization and heading during flight. Secondly, a nose-mounted camera system was implemented to serve as a lofted targeting hub to investigate the feasibility of tracking drone swarms and guiding submunitions. Multiple tests conclude that aerodynamic stabilization will be required to dampen the effects of the targeting hub oscillations during target acquisition. Lastly, this study allowed for the design, development, and evaluation of a mechanism for stable separation of rocket stages at high terminal velocities by incorporating a hybrid system of a mechanical release and carbon dioxide chamber pressurization.

DeSimone, Jonathan K. **"Using Commercial Space Situational Awareness as a Verification Mechanism for Orbital Debris Mitigation."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2021.
https://hdl.handle.net/10945/67699
Abstract: Orbital debris is a space security problem, and the existing space debris mitigation framework is insufficient to achieve long-term space sustainability. Fortunately, recent developments in commercial space situational awareness (SSA) systems may provide an alternative solution. This thesis explores two research questions. First, could commercial SSA systems be used as a verification mechanism for space debris mitigation accountability? Second, how could such a verification regime lead to future enforceable space debris mitigation policy? To answer the first question, this thesis surveys the capabilities and limitations of the significant SSA technical infrastructures around the world. For the second research question, this thesis explores how commercial SSA systems could be used as a space debris verification mechanism in four possible future options. The four options are the status quo, international enforcement, domestic enforcement, and commercial best practices. This thesis concludes that commercial SSA systems could overcome the transparency concerns of existing government-run systems and that regulators should consider using commercial systems as the primary source of data for space debris mitigation verification. Policy and organizational changes will be needed to attain a verification regime that could enforce future legally binding space debris mitigation policies.

Fuller, Adam. **"Analysis of Practical Employment of Drag Enhanced De-Orbiting Devices for Midsized LEO Satellites."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2021.
https://hdl.handle.net/10945/70634
Abstract: The use of drag-enhancing devices for satellite de-orbit has been successfully demonstrated on small satellites, and analysis shows they can be a practical method for de-orbiting many midsized low-earth orbit (LEO) satellites. A satellite's mass, orbital regime, ballistic coefficient, and other characteristics delineate the techniques and trade-offs related to implementing a drag device as a de-orbiting tool. In addition to reviewing the successes of drag devices to date in de-orbited spacecraft, Rhatigan and Lan outlined the trade space available for expansion of this technology to a large range of midsize spacecraft. This study examines that trade space in more detail and with a wide span of existing midsized LEO satellites. Through the analysis of these satellite characteristics and orbital regimes, this study suggests that the potential for fuel mass savings exists for a significant percentage of the midsized satellites. Furthermore, satellites that would still require some propulsion to de-orbit within 25 years show similar fuel mass savings. Drag-enhancing device requirements driven by this study are shown to be achievable within the scope of existing prototypes and realistic drag device designs.

Hansen, James E. **"High Altitude Balloons for Special Operations Forces: Supplementing Space with Stratospheric Solutions."** Master's thesis - Defense Analysis (Astronautics) & Space Systems Operations, Naval Postgraduate School, 2021.
https://hdl.handle.net/10945/67730
Abstract: The U.S. military depends on space-based technology for communication, remote sensing, and position, navigation, and timing (PNT). Changing international dynamics in Great Power Competition, specifically the increase in antisatellite testing and development, threaten the space-based capabilities military forces utilize, including Special Operations Forces. In 2006, the Department of Defense developed the Operationally Responsive Space initiative which focused on decreasing the requisite time to place military satellites in orbit following asset loss; however, there is still no way to rapidly reconstitute space-based capabilities that have been compromised. As the space domain becomes increasingly contested, high altitude balloons (HABs) can offer a quick and efficient method to bridge the time gap between the loss of a space asset and its replacement. However, HABs require modularity to improve the time efficiency of payload integration. The purpose of this study is to develop a modular HAB bus, termed the Bento Box, designed to operate independently or integrated in a fixed-wing marsupial vehicle for precision recovery. The integration of three payloads into the Bento Box demonstrates the modularity of the structure, one of which is a software defined radio reconfigured as a bent-pipe communications payload to relay video transmission signals. The study concludes with a field test of the HAB-suspended Bento Box for beyond line-of-sight video relay between maneuver elements.

Hardy, Ian A. **"Planar Electromechanical Robotic Manipulation System to Enable Unmanned Spacecraft Servicing (PERSEUS)."** Master's thesis - Astronautical Engineering, Naval Postgraduate School, 2021.
https://hdl.handle.net/10945/67732
Abstract: Rising numbers of aging spacecraft and new missions demand the development of novel approaches to perform various tasks in orbit. Complex servicing and assembly missions have been successfully completed by human astronauts in the past. However, currently available human-rated vehicles are not capable of accessing all relevant orbital locations, nor are there enough assets available for human operators to service all essential payloads directly. If sufficient capability to perform simple tasks remotely could be provided via a robotic manipulator, it may be possible to meet the servicing needs of a far greater number of missions at a lower program cost and without requiring risky extravehicular activities.
The aim of this study is to develop a remote-operated robotic system capable of performing relevant tasks when mounted to a planar floating spacecraft simulator operating on an air bearing table. This system, known as PERSEUS, possesses three revolute joints to allow

postural redundancy within a large workspace and a rapidly reconfigurable end-effector that enables simulation of various maneuvers for different planar orientations. When mounted to a simulated spacecraft, PERSEUS offers capability to simulate various grapple and hopping maneuvers representative of what may be required to inspect and service a host payload.

Ho, Kenny L. **"The Technological and Economic Feasibility of Asteroid Mining."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2021.
https://hdl.handle.net/10945/67738
Abstract: The objective of this thesis is to determine the technological and economic feasibility of asteroid mining. This thesis elaborates on why the key technological development should be further developing water extraction and manufacturing techniques. This secondary research was conducted with a survey of the technical and economic conclusions of many books, conference papers, and journal articles. Even though a mobile in-situ water extractor has demonstrated water extraction capabilities, the technology is not yet ready to be utilized in an actual asteroid mining architecture in the harsh climates of outer space. This thesis concludes that asteroid mining will be technologically feasible but will only be economically feasible upon further refinement of water manufacturing techniques on celestial bodies. This thesis recommends further investment into water extraction and manufacturing techniques from commercial companies and the government in order to increase the economic viability of asteroid mining.

Kempisty, Mitchell A. **"Minimizing Star Tracker Occultations for NASA's Lunar Reconnaissance Orbiter in Sun-Safe Mode."** Master's thesis - Astronautical Engineering, Naval Postgraduate School, 2021. https://hdl.handle.net/10945/68724
Abstract: Due to degradation of the NASA's Lunar Reconnaissance Orbiter's (LRO) Inertial Measurement Unit, the LRO relies solely on its star trackers to maintain gyroless attitude control. In the event of an anomaly, the LRO is placed in sun-safe mode in order to reestablish normal operation, which constrains its attitude. While in sun-safe mode, the LRO's star trackers experience occultations from local orbiting bodies and cannot maintain an attitude solution during these periods. This poses the risk of total loss of the spacecraft due to tumbling or depleted power supply. This thesis provides mission operators with a software-based tool for determining alternate sun-safe attitudes that reduce the occultation time, minimizing operational risk. Ephemeris data from orbiting bodies and the LRO are utilized to investigate occultation occurrences. Periods of star tracker occultations for any given time frame are determined based on the LRO's fixed attitude. The goal of this thesis is to iterate alternate attitudes to define the ideal attitude that minimizes occultation occurrences. Additionally, data analysis is conducted to determine the ideal attitude update frequency for sun-safe mode based on operational constraints. The design of this software-based tool yields appropriate results for acquiring an ideal attitude solution for minimizing star tracker occultations, giving mission operators the freedom to choose attitude constraints, simulation fidelity, and attitude update frequency.

Marczewski, Timothy J. **"Machine Learning in Mobile CubeSat Command and Control (MC3) Ground Stations."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2021.
https://hdl.handle.net/10945/67771
Abstract: The Mobile CubeSat Command and Control (MC3) ground station network is a program designed to enable many organizations to command and control very small satellites (or CubeSats) in low-earth orbit. The MC3 network currently consists of ground stations that are geographically dispersed and utilize non-standard configurations of commercial off-the-shelf equipment. The non-standard configuration of each location poses a challenge for the small staff of MC3 network operators who monitor network and ground station health status. These operators rely on software and automation to ensure the MC3 network is healthy and can support any organization's mission. However, the problem is that a normal state in one location can look different from the normal state at another location in terms of equipment and, therefore, health status. Determining the normal state using machine learning will

facilitate further analysis of ground station health and the implementation of near-real-time health status monitoring to augment the MC3 network operators' capabilities. The research focused on using the K-means++ unsupervised machine learning clustering algorithm to model the normal state. This research could not conclusively determine the normal state of the NPS MC3 ground station, but it does establish a launch point for further work.

Philbin, Brendan R. **"Impact of Injector Fabrication Technique on the Injection and Atomization of JP-10 for High-Speed Aero-Propulsion Systems."** Master's thesis - Astronautical Engineering, Naval Postgraduate School, 2021. https://hdl.handle.net/10945/68371
Abstract: Effective liquid fuel injection on future high-speed aero-propulsion systems is a critical requirement for high performance in volume-limited flight vehicles. The use of emerging manufacturing methods can potentially deliver favorable injection properties while allowing for complex design integration flexibility. The injection properties were characterized for conventional and alternative fabrication methods, including additive manufacturing, laser drilling, electric discharge machining, and platelet techniques. ANSYS Volume of Fluids-Discrete Phase Model simulations modeled the injection and atomization of JP-10 into a simulated engine environment, and the results were compared to experimental images for similar conditions. The experimental setup utilized planar laser-induced fluorescence to visualize the central jet cross-sectional trajectory of each injector type. This work added a dynamic lateral translation method for additional measurement planes across multiple jet orifices. Computer simulations to date have overpredicted the jet penetration characteristics when modeled as a single jet, ignoring geometry details such as port roughness. The influence of neighboring jets appears to increase the perceived air flow blockage and reduce the effective local fuel-air momentum ratios as fuel flow rates increase. This observation results in the requirement to model adjacent fuel jets to better capture the jet penetration and atomization trends.

Robey, Daniel L. **"Development, Integration, and Evaluation of Lightweight Materials for CubeSat Architectures."** Master's thesis - Astronautical Engineering, Naval Postgraduate School, 2021. https://hdl.handle.net/10945/68740
Abstract: Reductions in size, weight, and power requirements have been continuously sought for space systems. With small satellite technology continuing to leverage the miniaturization of electronics, pushing the boundaries of size and weight is a synergistic effort that enables the development of national capabilities in space. Currently, small satellite technology is often limited by the temperature limits of certain components, such as processors and batteries, and the high costs of placing them in orbit. The effort described herein is the additive manufacturing approach pursued to develop, fabricate, and integrate lightweight materials on a CubeSat. The hypothesis was that commercial filaments could be used to 3D print a radio housing that would have sufficient electrical, mechanical, and thermal properties to replace the original 6061 aluminum alloy. Some of the materials tested included carbon nanotube epoxy composites, carbon fiber reinforced nylon, carbon fiber reinforced polyethylene terephthalate-glycol, polycaprolactone infused with copper, and combinations of the filaments. Diverse radio housing samples were fabricated, integrated, and tested. Additively manufactured parts resulted in acceptable, RF shielding and mechanical and thermal conductivity values. Additionally, there was an 86% savings for cost and 80% less weight than the original aluminum alloy, proving the potential that other material and manufacturing approaches could have in developing CubeSats.

Smithson, Michael S. **"Wargaming Reliance on Commercial Space Partners: A Determination of Guiding Principles and Applications."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2021.
https://hdl.handle.net/10945/67816
Abstract: The 2010s saw a revolution in the space industry leading to the commercial proliferation of space technologies once reserved for national space programs and militaries, dubbed by many as Space 2.0. This rapid rebalancing of capabilities from traditional state actors to commercial entities contributed to a reevaluation of U.S. space institutions and practices resulting in an increased U.S. military reliance on commercial entities to build space capability, capacity, and resilience. To that end, there is renewed interest in discerning the impacts of this expanded commercial space reliance on current U.S. military doctrine, thus placing new demands on the practice of wargaming among the U.S. military services. Specifically, wargaming must now account for this increased reliance by establishing guiding principles and wargaming methodologies to properly account for this revolution in space-based capabilities. This thesis addresses this problem by sampling the scope of commercial space capabilities, evaluating governing policy and doctrine, and examining a representative sample of the U.S. military's reliance on commercial space. The unique qualities of commercial space are evaluated to identify a list of guiding principles for wargaming applications. Then, wargaming methodologies that encompass these guiding principles are identified and proposed. Finally, these principles are applied to the USMC's Assassin's Mace wargame to demonstrate and evaluate their utility and application.

Stokes, James C. **"A Cooperative Space Strategy for the Arctic: Policy, Strategy and Operational Aspects of Polar Great Power Competition."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2021.
https://hdl.handle.net/10945/67820
Abstract: The Arctic is an emerging theater of strategic importance. Opening sea lines of communication and increased access to Arctic resources are forcing U.S. strategic planners and decision makers to address regional challenges. The reemergence of polar great power competition, coupled with rapid climate change, has drastically altered the strategic demand for space capabilities within the region. This thesis explored how the United States might benefit from a cooperative space strategy for the Arctic and whether the United States must build collaborative space capacity within the Arctic to achieve its stated strategic objectives within the region. While U.S. strategists have presented a clear case for strategic engagement and cooperation in the High North, the United States currently lacks a comprehensive Arctic strategy for space that encompasses the challenges, opportunities, and existing capabilities and gaps of U.S. allies and partners in the region related to the space domain. Although U.S. Arctic strategies have consistently highlighted the fundamental necessity to enhance Arctic domain awareness and the political and geostrategic challenges that the United States faces within the Arctic region, these strategies lack an overarching framework for allied and partner space cooperation to achieve these effects. This thesis investigates how the United States builds allied and partner space cooperation in the Arctic to reinforce U.S. strategic interests in the region.

Wistner, II, Stephen A. **"Autonomous Assessment of Satellite Ground Station Health."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2021.
https://hdl.handle.net/10945/68808
Abstract: The objective of the study was to develop the initial capabilities enabling the eventual automation of an antenna gain-to-noise-temperature (G/T) measurement process using a software defined radio. This research investigated how to improve the Mobile Cubesat Command and Control (MC3) network's ability to remotely monitor a ground station's health. Previous thesis work was leveraged to collect baseline data and process it using software created by the Space Dynamics Laboratory for the MC3 program. The thesis required hands-on use of the NPS MC3 ground station and other stations on the network. The results of this thesis demonstrate that a software defined radio is capable of collecting and processing radio frequency signals from the sun and cold sky to produce a G/T value with enough fidelity to

assess the health of the station's downlink radio frequency chain. Continued expansion of the collected frequency range by the software defined radio is recommended to provide a broader assessment of the antenna's sensitivity to weak, space-borne signals.

Yoo, Brian. **"Improving Management of Commercial Satellite Mega-Constellations."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2021. https://hdl.handle.net/10945/67837

Abstract: Large commercial satellite constellations, colloquially nicknamed "mega-constellations," are providing improved capabilities for satellite operators and enhanced services for terrestrial users. While so, the environment in which these large space architectures operate, low Earth orbit, is cluttered with active satellites and littered with orbital debris. If not properly managed, commercial satellite mega-constellations could worsen the space environment for all space operators as they inherently involve more satellites and thus more risk. This thesis examines the United States' management of commercial satellites in three segments: pre-launch, on-orbit, and post-mission. This thesis further analyzes the entities, documents, and processes involved in the U.S. management of commercial satellites and identifies areas of concern raised by the looming rise of commercial satellite mega-constellations. Recommended improvements to the management framework address these concerns and discuss the (1) implementation of "core safety minimums," (2) establishment of rules for day-to-day satellite operations, (3) establishment of a set of core definitions and standards, (4) establishment and empowerment of a national entity for space situational awareness and space traffic management, (5) incentivization of post-mission disposal, and (6) reduction of post-mission orbit lifetime limits for expended satellites in decaying satellites.

2020

Bhatt, Anish H. **"Development of a Wideband THz Focal Plane Array for Space Applications."** Master's thesis - Applied Physics, Naval Postgraduate School, 2020.
https://hdl.handle.net/10945/65381
Abstract: This thesis builds upon the research being conducted in the Sensor Research Laboratory in the Physics Department at the Naval Postgraduate School (NPS) in collaboration with the Space Systems Academic Group. The goal is to contribute to the development of MEMS terahertz (THz) to infrared (IR) converters for real-time imaging, with potential applications to the space environment. The NPS MEMS THz-to-IR converters are typically thermal sensors, with one side sensitive to THz and the other side emissive in the long wave infrared (LWIR). The sensor heats up upon absorbing incoming THz radiation, and the subsequent rise in temperature can be probed by a commercial LWIR camera. A focal plane array (FPA) of such sensors translates the THz scene to an IR image, captured by the camera. The simplicity of this concept allows the FPA to be used as a simple attachment for IR cameras. The main advantage of this approach is that there is no need for electronics or complex optical readouts, making it very attractive for use in small satellites. The objective of this thesis is to design a MEMS THz-to-IR converter FPA with broadband capabilities. The main requirements are sensitivity between 0.5 and 10 THz and emissivity only on the band of the LWIR camera (7–14 μm). The research is constrained by requirements that allow integration onto a CubeSat (Cubic Compartmentalized Satellite) for concept demonstration in the space environment (specifically low Earth orbit) in future work.

Brandt, Camron A. **"Development of a Multistage Rocket Test Platform to Deliver CubeSat Form Factor to Near-Space Altitudes."** Master's thesis - Astronautical Engineering, Naval Postgraduate School, 2020.
https://hdl.handle.net/10945/66594
Abstract: The Naval Postgraduate School (NPS) Small Satellite Lab places heavy emphasis on the research, development, and integration of emerging technologies on future spacecraft. An integral part of the advancement of these technologies is the ability to test them in real-world environmental conditions. CubeSats remain a viable choice for rapid prototyping and proof-of-concept testing. Delivering CubeSats to near-space environments is a method of demonstrating the feasibility of these new technologies. Amateur high-power rocketry offers an additional platform to augment the already existing high-altitude balloons by delivering payloads containing the new technologies and CubeSat form factor small satellites to near-space environments. Previous NPS research has produced a single stage high-power rocket capable of attaining an approximate altitude of 11.9 km (39,000 feet) above ground level. This thesis applies optimal control theory to develop a multi-stage rocket capable of altitudes in excess of what was previously reached by both high-altitude balloons and the previously designed high-power rocket.

Hill, Rachel P. **"Commercial Geosynchronous Satellite Servicing."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2020.
https://hdl.handle.net/10945/65546
Abstract: On-orbit servicing (OOS) of satellites has been a significant goal since the early 1980s. Once considered feasible for satellites operating in low earth orbit (LEO) when the space shuttle program was operational, providing OOS for satellites operating in geostationary orbit (GEO) always has been beyond reach. The advancement of robotics and artificial intelligence (AI) has finally opened up the possibility of OOS for all orbital regimes. The aim of this thesis is to investigate what has been already proposed for OOS, identify the initial satellite subsystems that could benefit from OOS missions, and determine whether or not OOS can be made to be cost effective. By tracking and categorizing on-orbit satellite failures, a pattern begins to emerge about which subsystems are more likely to fail on orbit. From there, subsystem hardware components can be identified for potential replacement on legacy satellites and for design modification. Proving the ability to service legacy satellites will pave

the future of satellite design and capability. Ideally, as the technology progresses, all satellites will move to a more modular design thus saving money and materials. By using current models and cost analysis, the feasibility of OOS can be demonstrated.

Liu, Christopher Y. **"Radar-Embedded SATCOM with Deep Neural Network Demodulation."** Master's thesis - Astronautical Engineering, Naval Postgraduate School, 2020.
https://hdl.handle.net/10945/70445
Abstract: In this work, the feasibility, design, and implementation of radar-embedded communications with satellite applications are investigated. We design a deep neural network (DNN) machine learning detector to demodulate SATCOM data. The performance result is compared with the detection method of using maximum likelihood estimation (MLE) to estimate the amplitude and phase of the radar signal, which is followed by a maximum likelihood detection (MLD) receiver. Pulsed radar and linear frequency modulation (LFM) waveforms are chosen to embed communications symbols. Quaternary phase-shift keying (QPSK) and eight phase-shift keying (8PSK) modulations are used for illustration. In this work, three DNN demodulators for radar-embedded communications are developed. One of the DNN detectors actually outperforms the MLD demodulator and is shown to be robust for pulsed radar-embedded communications. One of our goals is to embed satellite communications into LFM waveform, which is used in synthetic aperture radar (SAR). The DNN works well for LFM radar-embedded communications when the received LFM phase offset is removed a priori. However, the DNN symbol error rate (SER) performance suffers when the LFM phase offset is introduced for large RCR. Lastly, we perform laboratory transmission and reception tests: a) shielded cable and b) over-the-air (OTA) tests. It is shown that pulsed radar-embedded communication is feasible with both MLE-MLD and DNN detectors with reasonable SER performance.

Nichols, Samuel J. **"De-Orbiting Drag Sail."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2020.
https://hdl.handle.net/10945/65410
Abstract: This thesis examined the possibility of developing a compact, reliable, and scalable drag sail to aid in de-orbiting satellites during their end-of-life operations. Using a current prototype, we created and tested a full-scale drag sail. We also developed a reliable mechanism that both retains the drag sail in a stowed configuration to prevent mission obstruction and, when commanded, allows a smooth and successful deployment.

Raisch, Kelly M. **"Additive Manufacturing of Ceramic Composites for Thermal Protection Systems."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2020.
https://hdl.handle.net/10945/65427
Abstract: The study and use of the space domain, including the recent reinvigoration of manned space exploration to the moon and beyond, drives the search for higher-performance materials for spacecraft thermal protection systems (TPSs). Ceramics and high-performance carbon both exhibit material properties that are suitable for TPS applications, but their performance can be maximized using additive manufacturing (AM) methods. Vibration-assisted printing (VAP) is a newly developed AM process that can fabricate parts using highly viscous mixtures of ceramic-forming polymers with solid ceramic particles. This work explores the AM of a ceramic sandwich TPS utilizing VAP. The TPS outer layers consist of silicon carbide (SiC) for high oxidation resistance, high melting point, and low thermal conductivity. A thin middle layer consists of a carbon-based material that provides high in-plane thermal conductivity to redistribute heat. Numerical simulations showed that this configuration was effective at reducing maximum temperatures under simulated re-entry conditions. A highly viscous mixture was prepared from a polycarbosilane polymer and pure SiC powder, which could be 3D-printed using VAP, and the middle layers for assembly were printed via standard thermoplastic extrusion using carbon-loaded or carbon-fiber-loaded filaments. SiC components were cured up to 248.8°C and pyrolyzed at up to 1,600°C, and were characterized via SEM, EDS, and XRD and tested for compressive strength.

Trent, Morgan C. **"Design of a Regeneratively Cooled Bi-Propellant Rocket Engine Using Additive Manufacturing."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2020.
https://hdl.handle.net/10945/65455
Abstract: Empirical heat transfer values and thermodynamic models were verified and expanded for a uni-element film-cooled liquid rocket engine operating on a gaseous oxygen and RP-1 mixture. This effort was motivated by the likely reduction of the overall engine mass by integrating regenerative cooling channels directly into the combustion chamber and nozzle walls through the use of additive manufacturing. The data was collected for a range of operating conditions from 1.77 to 2.29 oxidizer-to-fuel mass mixture ratio and 9.65% to 19.69% film cooling. The combustion chamber of the engine experienced damage at heat flux values of 4.54 MW/m2 that occurred at a chamber pressure of 6.96 MPa, a mixture ratio of 2.0, and 9.59% film cooling. The data collected was used with computational tools to develop a novel integrated chamber-nozzle engine design for both regenerative cooling and film cooling conditions. The final design possessed less than 6% variation of flow though the 18 regenerative liner passages and was predicted to be able to handle the current and expected heat transfer values. The unit was printed using Stainless Steel 17-4PH with additive manufacturing techniques but will need to be qualified with future open and closed-loop testing to evaluate the delivered regenerative cooling effectiveness.

West, Logan T. **"Design, Build and Test of a Low-Cost, High-Bandwidth X-Band Software-Defined Radio for CubeSats."** Master's thesis - Astronautical Engineering, Naval Postgraduate School, 2020.
https://hdl.handle.net/10945/66741
Abstract: The objective of this research was to design, build, and test the next iteration of a low-cost, high-bandwidth X-band software-defined radio (SDR). The flight version of this iteration of the payload will be integrated into a commercially provided 6U bus to transmit and receive data, commands, and telemetry between the satellite and the MC3 network. The spacecraft reference design included two other payloads and used the Astro Digital Corvus-6 bus as the baseline for defining payload-bus-ground interfaces. This project utilized MATLAB Simulink to program the SDR. The SDR will primarily operate in the store-and-forward mode for transmissions when in line-of-sight of a ground station. The up/down convert board was designed, and manufacturing options were explored. Additionally, this project finalized the mechanical enclosure and bus interfaces. The payload aimed to maintain a 0.5U CubeSat form-factor and achieve a data rate of up to 10 Mbps with 1e-5 bit error rate. Following design and construction, the hardware and software components were subjected to functional end-to-end testing to evaluate performance. Further flight qualification will subject the payload to environmental testing to ensure survivability through launch and the expected low-Earth orbit environment.

Wood, Samuel H. **"Trade Study of Commercial Software-Defined Radio Technologies for Small Satellite Ground Station Network Command and Control Applications."** Master's thesis - Systems Technology (Command, Control, and Communications) & Space Systems Operations, Naval Postgraduate School, 2020.
https://hdl.handle.net/10945/65475
Abstract: The Mobile CubeSat Command and Control (MC3) ground station network headquartered at the Naval Postgraduate School monitors and controls small satellites in support of various U.S. government, Department of Defense, public university, and commercial partner missions. In order to conduct the necessary Command and Control functions with the on-orbit satellites, MC3-networked ground stations utilize the baseline NI USRP-2292 software-defined radio (SDR) to transmit and receive command messages through ultra-high frequency and S-band RF signals. Two alternative high-end commercial systems have been advertised to provide superior performance and functionality to that of the baseline USRP devices. This thesis documents the trade study performed between the baseline NI USRP-2922, the Ettus Research USRP B205mini-i, the Kratos RT Logic quantumRadio, and the AMERGINT satTRAC system. The study investigated and evaluated the performance,

functionality, and suitability of these SDR technologies for implementation in the MC3 ground station network. The results were analyzed and compared for applicability to other comparable university stations, commercial networks, and government applications. The research culminated in a characterization of these four SDR devices, a description of their suitability in the MC3 network, and a comparative analysis of their operational functionality and any limitations.

Wooten, Kenneth N. **"Additive Manufacturing of Silicon Carbide (SIC) Ceramic Rocket Nozzles."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2020. https://hdl.handle.net/10945/65476

Abstract: Rocket motor nozzles are typically made of materials such as graphite and fiber-reinforced phenolics or epoxies with low erosion rates, relatively low manufacturing costs, and/or reduced weight. Additive manufacturing (AM) methods enable unique control of geometry and composition and can improve the weight and thermal performance of rocket nozzles. A newly developed AM process called vibration assisted printing (VAP) can process a unique combination of ceramic-forming polymer binders with a large amount of solid particles at very high solid loadings and viscosities. This research investigated the formulation, pre-processing and post-processing of these materials, determined their final microstructure and phase composition, and compared them to some of the materials utilized in rockets today. Some of the parameters investigated included mixture ratio, curing temperature, and sintering temperature of silicon carbide (SiC)-ceramic forming polymer particles. These mixtures were used for 3D printing of SiC-ceramic matrix/SiC composite parts. The results of the study will help improve the performance of modern-day rockets and other applications within the aerospace industry.

2019

Allen, Jr., Tony. **"Optimization of Multi-Junction Solar Cell for Space Applications Modeled with Ruby, MATLAB, and Silvaco."** Master's thesis - Electrical Engineering, Naval Postgraduate School, 2019.
https://hdl.handle.net/10945/64137
Abstract: The purpose of this research is to document further research into the optimization techniques investigated by James Walsh and applied to Multi-junction Solar Cells. Walsh performed his research with the Near Orthogonal Latin Hypercube (NOLH) in order to optimize the design specifications for each layer of solar cell thickness and doping concentration. Walsh at the same time evaluated cell performance under the radiation effects of the space environment. This research performed a similar analysis, except for the radiation effects, but focused more on producing an algorithm that could be executed from single user input and significantly reducing the selected design space. This research produced an efficient program that seamlessly operates between Ruby, MATLAB, and Silvaco ATLAS in order to produce an optimal designed dual-junction solar cell for space applications, in a much smaller design space than the technique utilized by Walsh.

Anderson, Laura G. **"Satellite Tracking with Telescope and Software."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2019.
https://hdl.handle.net/10945/63462
Abstract: Space is becoming increasingly congested and contested as small satellites, to include CubeSats, are launched in greater numbers. The Space Systems Academic Group at the Naval Postgraduate School purchased an advanced commercial off-the-shelf (COTS) telescope from Meade Instruments (model LX600) with the goal of tracking CubeSats and as an educational tool for postgraduate students. This thesis specifies a plan, based on research and proof-of-concept testing, for NPS to create an automated (closed-loop) optical telescope system capable of detecting and tracking CubeSats in low Earth orbit. Satellite tracking will be a new capability for NPS, and will allow for future work in multiple areas, to include orbit determination, space situational awareness, and laser communications. This thesis recommends additional equipment, dedicated software, and permanent staging of the telescope system in order to attain a closed-loop satellite tracking system with an optical telescope.

Archer, Stuart C. **"Modularization of Triple Fault-Tolerant Designs (TFTD)."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2019.
https://hdl.handle.net/10945/63984
Abstract: The configurable fault-tolerant processor (CFTP) project was intended to develop the means for a system to operate in areas which include frequent single-effect events (SEEs) similar to those caused by ionized radiation colliding with logic gates. Such errors are capable of degrading the functionality of a system and completely changing a state machine, such as is at the heart of most spacecrafts' processors. The method for this consisted of a field-programmable gate array (FPGA) being designed into a system which is capable of detecting and then correcting SEEs. The system was designed by many students. This project will take that design, which launched into space earlier this year, and reduce it to modules which can be uploaded individually, built around a core which will be part of the existing triple fault-tolerant design (TFTD). Modularizing the code allows more experiments to be simultaneously performed in the future by changing the architecture of the system to upload specific modules to specified addresses. This will allow smaller uploads and code tweaks, without incurring long upload times, and more frequent updates to run specific tests ad hoc. Research and development conducted for this thesis has demonstrated the capability to inject configuration errors into the current design and the TFTD's ability to detect those and similar errors, contributing to a better understanding of the TFTD.

Bischoff, Greg. **"X-Band Software-Defined Radio for CubeSat Applications."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2019.
https://hdl.handle.net/10945/63431
Abstract: Software-defined radios (SDRs) are used in many communications applications and offer flexibility in designing a communication network by offering rapid configuration changes after the radio is already produced. This is of interest in the small satellite industry, where small, lightweight, low-cost, and programmable radios will be needed for a wide array of upcoming missions of increasing complexity. Previous Naval Postgraduate School (NPS) research has produced a C-band SDR payload in a 1U CubeSat form factor. The X-band of the radio frequency spectrum offers more bandwidth, and opens the possibility of higher data rate transmissions. The objective for this project was to build an X-band SDR that can be used in future NPS research and flown on multiple platforms, including high altitude balloons, high altitude rockets, and CubeSats. This project built on previous C-band SDR research by converting the transmissions to X-band, expanding the over-air software protocol, implementing a new waveform, increasing the over-air data rate, and assessing the overall performance of the system.

Cruz Ojeda, Armando. **"Feasibility Study of Optimization Models for the MEXSAT System."** Master's thesis - Systems Technology (Command, Control, and Communications), Naval Postgraduate School, 2019.
https://hdl.handle.net/10945/62707
Abstract: The Mexican Satellite (MEXSAT) system has a limited lifetime; therefore, it is crucial to evaluate and compare the performance of alternative techniques to achieve space communications, which could possibly improve the Mexican space communication capabilities. Furthermore, when compared to MEXSAT, the O3b constellation concept seemed to offer several benefits. The purpose of this thesis was to investigate the feasibility of acquiring satellite communications with more efficient performance for the Mexican Navy (SEMAR) as the main stakeholder, by adopting this O3b constellation concept. This research used STK software to develop, analyze, and compare different proposed satellite constellation models and their communication links with the current MEXSAT performance in order to evaluate the feasibility of getting a more capable and functional satellite constellation for Mexico. When modeling and comparing both communication capabilities, the research found antenna gain values were crucial to the efficiency of the links. Moreover, rain attenuation values were critical and significantly affected the performance of the modeled links at Medium Earth Orbit. Ultimately, our simulated results showed that the performance of the current MEXSAT system was superior to the modeled O3b constellations.

Gilley, Joseph. **"Reconstruction of Satellite Decryption and Data Handling Processes."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2019.
https://hdl.handle.net/10945/62698
Abstract: This study examines how to reconstruct a satellite decryption process from source information. It examines how cryptographic algorithms are implemented in software and what software components are required to access data in a useable format. This examination enabled the reverse engineering and reconstruction of the decoding processes utilized by the three PropCubes: Merryweather, Fauna, and Flora. Transmitted data from these PropCubes was analyzed to verify the validity of the developed decryption and data handling Python scripts. A concept of operations for implementing the reconstructed decryption and data handling processes in real-time is discussed in this research.

Johnson, Jordan M. **"The Great Space Force Debate: A Way Forward from the Past?"** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2019.
https://hdl.handle.net/10945/63989
Abstract: The concept of a "Space Force" has been debated in rooms at the Pentagon, on social media, and even as a potential series on Netflix, yet space operations have been an integral part of the U.S. armed forces for about 40 years. U.S. interest in space began as an urgent move to prove our nation's competitiveness during the Cold War. Today, the initiative

to have a Space Force is rooted in the nationalism of President Donald Trump. The Space Policy Directive-4 signed by Trump is waiting for congressional approval, so a historical review of the role of space within the U.S. military is needed. This thesis analyzes the roles the Army, Air Force, and Navy have already played within the combined space effort. Through this historical analysis, this study offers a comparative examination of the space interests of each of the three branches of service, showing how each defines and views space, and addresses space organization within the services. The study concludes that the Air Force Space Command should remain under the U.S. Air Force and be renamed the Space Corps with both United States Space Command and the Space Corps being the central chain of command for all the services.

Pierce, Dillon T. **"Development of a Rocket Test Platform Capable of Delivering Standard Dimension Payloads to Near-Space Altitudes."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2019.
https://hdl.handle.net/10945/62696
Abstract: Within the NPS Small Satellite Lab, research and development of emerging technologies and their implementation as CubeSat payloads has continued to be a focus of hands-on, lab-based academics. Testing of these student-built CubeSats in real-world environmental conditions began with the high-altitude balloon project in which large Nomex weather balloons were used to carry student-built CubeSat payloads to near-space altitudes. Since the inaugural flight in 2011, the high-altitude balloon project has generated interest from both senior civilian and military leadership, as the academic and military utility of such a program is readily apparent. Building upon the success of the program, this thesis seeks to complement the capabilities of the high-altitude balloon as an academic education tool and military payload delivery vehicle through the development of a high-power rocket program within the NPS Space Systems Academic Group. In addition to providing procedures and documentation as to the requirements for establishing a high-power rocket program, this thesis details the design, construction, and proof-of-concept flight of a reusable rocket capable of delivering standard dimension payloads to near-space altitudes. Results from several rocket flights are then used to explore the academic and military utility of a sustainable high-power rocket program.

Pross, John W. **"Filling the Gap: Rocket Delivered Short-Term Expeditionary Beyond Line-of-Sight Narrowband Communications Relay."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2019.
https://hdl.handle.net/10945/62697
Abstract: The current Department of Defense (DoD) satellite communications (SATCOM) network consists of large, exquisite, and expensive constellations providing service across the radio frequency spectrum. However, the current SATCOM architecture is vulnerable to adversary actions including interference, jamming, directed energy, and antisatellite weapons. Despite the rise in adversary threats, the DoD continues to grow more reliant on SATCOM services in execution of all seven joint warfighting functions. The Marine Corps Operating Concept acknowledges that traditional beyond line-of-sight (BLOS) communications capabilities will be severely degraded or non-existent in the future fight. This research demonstrates a near-term solution that increases resiliency in BLOS communications consisting of a rocket-delivered expeditionary narrowband radio relay with an applicable use case. The payload of the relay consists of a software-defined radio controlled by a single-board computer and demonstrates resiliency by cross-banding signals between very high frequency and ultra high frequency transmit and receive frequencies, respectively. After a rigorous design and test process, this research culminated with an actual demonstration over the air and an attempted delivery by an actual rocket to a target altitude of 30,000 feet.

Shapiro, Jessica. **"Tethered Spacecraft Systems for Active Debris Removal."** Master's thesis - Astronautical Engineering, Naval Postgraduate School, 2019.
https://hdl.handle.net/10945/62294
Abstract: Orbital debris will increase dramatically unless active debris removal methods are implemented. Tethered methods of active debris removal present an intriguing solution that should be investigated and the benefits compared to other researched methods of active debris removal. This study consists of applications of tethered space systems and active debris removal methods with a focus on tether-based momentum exchange systems in an effort to determine if a tethered propellantless debris removal solution is a viable one. The debris will be assumed to have been captured, with the tether attached to the center of mass of both the debris and the removal vehicle. The debris analyzed has simplified characteristics based on Hubble Space Telescope. The results of this study, conducted primarily using MATLAB and Simulink numerical integration methods, explore the dynamics of tethered satellite systems and compare the results of different removal methods, including the addition of a drag sail via a long tether, tethered momentum exchange orbital transfers, and propulsive orbital transfers. The momentum exchange model explores effects of tether length and spin rate on the momentum exchange orbital transfer.

Verbeeck, Michelle L. **"Drag Enhancement Device Prototype for Mid-Size Spacecraft."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2019.
https://hdl.handle.net/10945/62699
Abstract: This study constructed a drag device to demonstrate and evaluate the benefits of including a drag enhancement device for spacecraft self-disposal in Low Earth Orbit (LEO). The study assessed the viability of drag enhancement device deployment and functionality for mid-size spacecraft using a scaled model constructed with polymer materials. While drag devices for CubeSats have been well-studied and demonstrated, the mid-size, LEO spacecraft class most commonly deployed by the Department of Defense has not. The motivation for self-disposal is policy driven. This research targeted a simple, cost-effective approach conducted using scaled models for proof-of-concept that will lead to the final development prototype demonstrating effective deployment and functionality. The prototypes were developed using available software tools such as computer-aided design NX and were tested for structural integrity, functionality, and mechanical deployment.

2018

Alsup, Katrina P. **"Robotic Spacecraft Hopping: Application and Analysis."** Master's thesis - Astronautical Engineering, Naval Postgraduate School, 2018.
https://hdl.handle.net/10945/61364
Abstract: This thesis will explore the hopping mobility approach for robotic vehicles used in Intra-Vehicular Activities (IVA) as an alternative mobility in space for small spacecraft equipped with robotic manipulators. A hopping maneuver uses the robotic manipulator to hop between two locations inside the host spacecraft. The maneuver is defined as three distinct phases: push, free-flying coast, and soft landing. Maneuvers such as hopping will be used to quickly move from one part of the host spacecraft to another, with little to no fuel consumption compared to zero-g climbing and propulsive free-flying. This thesis answers the question, "Is there an ideal mobility for use in space that uses zero propellant?" The concept of an IVA hopping maneuver was explored, analyzed and experimentally demonstrated in simulation. Simulation results of such a maneuver validate hopping as a mobility approach in space. Future work includes ground testing of the hopping maneuver and implementation onboard the International Space Station to demonstrate an on orbit–hopping maneuver.

Aslan, Asim Gokhan. **"Feasibility Analysis of Regional Timing and Positioning System for Turkey."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2018.
https://hdl.handle.net/10945/61197
Abstract: Space-based global positioning systems are three-dimensional measurement systems that use radio signals from a constellation of satellites orbiting the Earth. They comprise a satellite navigation system designed to provide instantaneous position, velocity, and time information almost anywhere on the globe at any time. This technology is used in numerous areas such as unmanned systems, missiles, commercial and military aviation. The United States' NAVSTAR Global Positioning System and Russian Global Navigation Satellite System (GNSS) are fully operational and used by different nations. Because of the technology's essentiality, most countries aim for independence; however, this is a big problem for developing or non-space faring countries because of the cost of the systems. To decrease the cost of a position navigation and timing (PNT) constellation, some nations develop regional PNT systems. In this research, GNSS systems, regional navigation satellite systems and satellite-based augmentation systems are analyzed, and an independent regional timing and positioning system satellite constellation over Turkish territory is reviewed using the AGI Systems Tool Kit software.

Breen, Nicole M. **"Can the Outer Space Treaty Prevent Conflicts in Orbit in the 21st Century?"** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2018.
https://hdl.handle.net/10945/59607
Abstract: The rapid increase of space activity in the 21st century has raised questions about the adequacy of the 1967 Outer Space Treaty (OST) to govern orbital activities and prevent future international conflicts. This thesis analyzes the OST's ability to address critical emerging problems across three issue areas: orbital space debris, the weaponization of space, and asteroid and Moon mining. It concludes by arguing that the language within the OST does not adequately address these emerging problems, which could lead to possible conflicts in each of these issue-areas. This thesis offers several possible policy recommendations for consideration by U.S. decision makers to promote a future framework of stability and longevity in the use of space: 1) transfer responsibility for tracking non-military satellites and space debris in low earth orbit (LEO) from the military to commercial space companies; 2) review the current 25-year guideline for de-orbiting satellites for adequacy; 3) propose a moratorium to China and Russia on further anti-satellite weapons (ASAT) testing; 4) prohibit nefarious behavior in space, rather than trying to prohibit dual-use technologies; 5) initiate talks with Russia and China to reevaluate and discuss the Moon Treaty; and 6) reach out to interested State Parties in the OST to coordinate future space mining legislation.

Correa de Souza, Marcello. **"NPS Terahertz Project: IR HAB Flight Testing and Integration."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2018.
https://hdl.handle.net/10945/58288
Abstract: Terahertz (THz) technology has become very attractive for space purposes. In this context, Department of Defense (DoD)-Space recently started to sponsor the THz Project at NPS to develop this technology for future space applications. The goal of this project is to develop a prototype THz imager that could be flown in space. Given the proposed THz architectures, the infrared (IR) imager is an appropriate first step in that direction. Therefore, this study is a relevant starting point for the THz Project at NPS since it shows the results of experiments using an IR camera integrated on high-altitude balloon (HAB) flights. The objective of this thesis is to study the integration concerns in order to evaluate possibilities and suggest appropriate configurations. This study provided relevant knowledge about a Raspberry Pi–controlled command and data handling board with a radio and an Electrical Power System for the main bus, designed 3D printed pieces, developed interfaces between cameras and boards, assembled and disassembled structures, managed weight / power / data budgets, and accomplished the launch and recovery operations. The recommendations at the end of this thesis indicate that better configurations should be adopted for the next stages of the project

Davis, Andrew S. **"Forestry Identification with LiDAR Waveform and Point Clouds."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2018.
https://hdl.handle.net/10945/59646
Abstract: The aim of this study was to analyze discrete and waveform data to improve existing Terrain Classification (TERCAT) capabilities. Light Detection and Ranging (LiDAR) data were collected over the Point Lobos State Park, which contains various buildings, vegetation, and man-made surfaces. Data were used from two separate airborne LiDAR systems, Optech Titan and Airborne Hydrography AB (AHAB) Chiroptera II. Classic standard point cloud analysis techniques were used with the discrete data. Waveform data were analyzed following a gridding or rasterization process to enable visualization and processing. Analysis approaches used were ENVI classification tools such as Support Vector Machines (SVM), Spectral Angle Mapper (SAM), Maximum Likelihood, and K-means to classify returns. Through the use of this analog to hyperspectral data analysis to classify vegetation and terrain, the results are that, by using the Support Vector Machines with full waveform data, we can successfully improve low vegetation classifiers by 40%, and differentiate tree types (Pine/Cypress) at 40–60% accuracy.

Forbes, Austin E. **"Sharing S-Band Communications to Conduct Small Satellite TT&C."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2018.
https://hdl.handle.net/10945/58295
Abstract: Electromagnetic (EM) spectrum management is an escalating concern in today's growing wireless market, and ensuring that the growing number of EM spectrum users have adequate access will become only harder and more expensive as the number of users of cellular phones and satellite operations continues to grow. Utilizing and effectively sharing available spectrum is an involved process with many users competing for access. With the ever-increasing demand for EM spectrum, the creation and utilization of policies and regulations that support and encourage the co-utilization of EM spectrum bands is of growing importance. The Mobile CubeSat Command and Control (MC3) ground station personnel at the Naval Postgraduate School (NPS) in Monterey, California, conducted a series of tests with local news station KION to determine the feasibility of simultaneously using an S-Band uplink frequency to conduct telemetry, tracking, and communications (TT&C) with NPS CubeSats while KION conducted its electronic news gathering (ENG) operations. The testing determined that conducting TT&C satellite operations above 7 degrees of antenna elevation does not impact ENG operations in Monterey. Our results may encourage spectrum co-utilization and ease the strain on the increasingly congested EM spectrum.

Herren, Kate J. **"Integration and Implication of Space Education at the United States Naval Academy."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2018. https://hdl.handle.net/10945/59681

Abstract: Space competency is critical to winning our future wars. Over the past 60 years, the United States Navy (USN) has played an essential role as an active enabler of space-based capabilities. In this day and age, when adversaries continue to mature their own space capabilities to deny U.S. capabilities, further developing space-based systems for Naval and Marine Corps operations is imperative. While the USN's professional Naval Space Cadre has grown in numbers and improved its proficiency in recent years, the USN must invest in space support to the warfighter in order to increase space-based fleet training that will strengthen the cadre as well as the end users. This thesis identifies gaps in the space-based education that is being provided to the Midshipmen at the United States Naval Academy. This study finds that the United States Naval Academy needs to increase awareness of the Navy and Marine Corps' reliance on space-based systems, and to emphasize the growing need for space professionals, through education. Expanding curricula to Midshipmen on space-based systems and operations could be the key to enhancing the Navy Space Cadre for the future and protecting warfighters.

Hanlon, Edward A. **"Design Strategies and Tactics to Defeat Co-Orbital Anti-Satellite Capabilities."** Master's thesis - Systems Engineering, Naval Postgraduate School, 2018. https://hdl.handle.net/10945/59677

Abstract: Spacecraft play an increasingly significant role in U.S. military operations. For adversaries looking to degrade U.S. capability to mitigate tactical advantage, this reliance provides another attack vector and represents a potential U.S. weakness. Recent technological developments have resulted in the increased proliferation of "attack" satellites. A strong understanding of the orbital domain and orbital dynamics is necessary to effectively evade these attackers. Much like the early days of aviation, space innovation has outpaced existing tactics, techniques and procedures. This thesis aims to provide an overview of the domain and possible evasive maneuvers to facilitate further tactics development. It begins with an overview of the threat landscape to provide background on what to expect and proceeds to discuss what positions of advantage are in space and how thrust commands translate to maneuvers at different time scales. It details the development of an engagement simulator and provides insight as to the effect of various evasion thrust patterns. From this, an evasion tactic is developed and tested in the simulator. This tactic proves effective in evading an aggressor while also demonstrating substantial fuel savings over alternative methods. Finally, different spacecraft parameters are compared to determine what hardware improvements provide the best evasive capability.

Kline, Sarah J. **"Flight Qualification of a Terahertz Imaging Camera as a CubeSat Payload."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2018. https://hdl.handle.net/10945/59702

Abstract: This thesis builds on the existing research of the Sensor Research Laboratory and the Space Systems Academic Group (SSAG) at the Naval Postgraduate School (NPS) to integrate an 80-micron terahertz (THz) imaging camera (TIC) as a CubeSat payload. This research investigates the potential utility of THz imaging and long-wave infrared (IR) imaging at room-temperature (20°C) cooling for applications of national interest like space situational awareness (SSA). Long-wave IR imaging capability already exists, and typically requires a large cryocooler to maintain cryogenic temperatures (3–70 K); efficient IR imaging at room temperature is an emerging technology. Additionally, this thesis examines the integration and test effort associated with flight qualifying the TIC engineering development unit (EDU) onto the SSAG-developed High Altitude Balloon (HAB) bus. This thesis contributes to the overall objective of integrating and flight qualifying the TIC as a payload compatible with a variety of buses. Integrating and testing the TIC EDU on a CubeSat attains focused research objectives of national interest and supports Department of Defense Space efforts in the utilization of very small satellites.

Koeppen, Nicholas R. **"Well-Conditioned Pseudospectral Optimal Control Methods and Their Applications."** Master's thesis - Engineering (Astronautical Engineering), Naval Postgraduate School, 2018.
https://hdl.handle.net/10945/63786
Abstract: Pseudospectral optimal control is an established discipline with flight-proven results. Aerospace applications have included the implementation of minimum-time and zero-propellant maneuvers on high-value space assets. Standard pseudospectral methods have been sufficient for these and other applications that do not require more than approximately 250 nodes. Currently, pseudospectral optimal control uses the Lagrange differential operator, D, which is ill-conditioned such that the condition number grows as O(n2) for first-order systems. Thus, applications in need of higher temporal resolution—such as satellite maneuver and collection planning—have relied upon suboptimal heuristics, inefficient algorithms, or optimal control via domain decomposition. In this thesis, well-conditioned pseudospectral optimal control methods are established, which use the Birkhoff integral operator that exhibits condition number stability of O(1). By forming a well-conditioned system, these methods expand the applicability of optimal control. For satellite maneuver planning, this means the ability to optimize long-duration, low-thrust orbital maneuvers. Satellite collection planning can also be solved with optimal control formulations based on nonsmooth calculus. These high-resolution applications require many more nodes than ill-conditioned methods allow. Even low-resolution optimal control problems can see improvements in computation time through stability.

Komma, Justin L. **"Mechatronics: The Development, Analysis, and Ground-Based Demonstrations of Robotic Spacecraft Hopping with a Manipulator."** Master's thesis - Astronautical Engineering, Naval Postgraduate School, 2018.
https://hdl.handle.net/10945/61207
Abstract: Astrobee is a robot designed by Intelligent Robotics Group at NASA Ames Research Center to operate inside of the International Space Station (ISS). The robot has a manipulator that is made up of various mechanical, electronic, and control systems. The designed purpose of the manipulator is to perch Astrobee in an effort to minimize power consumption. The study of grasping dynamics and hopping will lead to more efficient maneuvers that would not require propellant. Can the current Astrobee manipulator perform a propellantless maneuver by using its manipulator? This thesis reports the construction, design, integration, and testing of a robotic manipulator. A replica model of NASA's Astrobee manipulator, with 3 degrees of freedom (3-DOF), was constructed at the Spacecraft Research Laboratory (SRL) of Naval Postgraduate School (NPS) using commercial off-the-shelf (COTS) avionics. The control principle of the manipulator was correspondingly developed. Using the Python scripts, the user can easily interact and control the manipulator. Purposely developed test beds enabled to measure the maximum linear force required to remove the manipulator from a perched rail and determine the gripper slip angle of the manipulator from a three-dimensional (3D) printed ISS rail. We found that Astrobee's manipulator can perform propellantless maneuvers by tossing itself from one ISS rail to another ISS rail.

Leone, III, John J. **"CubeSat Pass Quality Analysis and Predictive Model."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2018.
https://hdl.handle.net/10945/59708
Abstract: The current ground station infrastructure of the Naval Postgraduate School (NPS) Mobile CubeSat Command and Control (MC3) Network can sufficiently manage the existing three CubeSats that it has been tasked to monitor and control. However, the projected growth in the quantity of these satellites will produce greater likelihood of conflicting passes, a condition where multiple CubeSats are above the horizon simultaneously with respect to a single ground station and are competing for limited downlink antenna assets. Consequently, as more CubeSats are placed in orbit, the ground stations that communicate with them need to become more efficient and require optimization strategies to make best use of the network. Using the MC3 historical data set for its PropCube satellites, this thesis creates a grading scale

that can be used to prioritize which PropCube should have antenna priority based on the expectation of downlinking data and when during the satellite's pass an operator should expect to capture that data. This value function can be used by an optimization program, such as that being developed in the NPS Small Satellite Laboratory, to maximize the data retrieved from a constellation of satellites. Additionally, the tools developed for analyzing and understanding MC3 PropCube passes can be used to determine value functions for other ground station networks in order to efficiently schedule CubeSat contacts.

Long, Bryan P. **"A Comparative Analysis of Future Space Orbital Transportation Systems."** Master's thesis - Systems Engineering Management, Naval Postgraduate School, 2018.
https://hdl.handle.net/10945/59710
Abstract: This thesis conducts a comparative analysis of future Orbital Transportation Systems (OTS). Near future rocket advancements are compared to future capabilities of a well-documented non–rocket based OTS, the space elevator transportation system. Technical and geopolitical impacts of both systems to future space exploration and the space industry are analyzed. Recent multiple new entrants into the space rocket industry are developing larger payload capacity rockets and driving down the cost per kg to orbit. These advances will lead to major improvements in the way spacecraft and satellite engineers will design their future systems with fewer payload constraints and lower total mission cost constraints. While beneficial, these advancements in rockets could have an adverse effect on the continuing efforts to develop alternate OTSs, such as the space elevator, by reducing the research and design (R&D) funding available for those systems. A space elevator offers the promise of consistent daily to-orbit transportation with a very large payload capacity at an extremely inexpensive cost. For these reasons, the space elevator system is worth the continued R&D investment to address major technical challenges in its continued development.

Lovdahl, Bianca L. **"Software-Defined Radio Payload Design for Cubesat and X-Band Communications."** Master's thesis - Astronautical Engineering, Naval Postgraduate School, 2018.
https://hdl.handle.net/10945/61218
Abstract: With traditional radio frequency (RF) bands becoming congested and the Department of Defense (DoD) expanding its efforts in the field of small satellites, the need for an on-orbit software-defined radio (SDR) has emerged. SDRs are a compact, off-the-shelf, low-cost, low-risk options for small satellite communication and can provide the flexibility of on-orbit configurability. This study includes the research toward the development of an on-orbit SDR CubeSat payload that can transmit on X-band spectrum (8–12 GHz). This band of interest can provide higher data rates and more bandwidth. Work in CubeSat transmitters and receivers supports development of national capabilities in space of benefit to warfighters. The payload designed, built, and tested for this research is called Com-Cube. Com-Cube utilizes hardware components and software considered for incorporation into a future CubeSat payload. Com-Cube was tested on a low altitude balloon (LAB) flight and demonstrated the transmission of images taken in-flight to a ground station via an amateur radio C-band frequency (5.75 GHz). This work directly supports a transmitter and receiver needed for future telemetry, tracking, and command (TT&C) and payload applications in the field of small satellites. This type of payload provides a test platform for further NPS research in the Mobile CubeSat Command and Control (MC3) ground station network operations and broadcast and receive experiments at frequencies of interest.

Manuel, Robert H. **"Coalition Space Operations: Exploring New Paths for Allied Partnership."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2018.
https://hdl.handle.net/10945/59715
Abstract: The use of satellites to support military operations has grown dramatically in recent years, which has increased the exposure of military satellite systems to targeting. To combat this risk to its space systems, the Department of Defense has prescribed increased military space cooperation with the United States' closest friends and allies. This thesis investigates the United States' history of partnering with three of its closest allies—France, Australia, and

Japan—since the dawn of the space age to see where the best opportunities for enhanced military space cooperation exist today. It finds that changes in the military space organizations, capabilities, and policies of these three allies since 2008 have significantly increased the ability of their militaries to collaborate fruitfully with the Department of Defense. Furthermore, aided by the ongoing growth of their military space cadres, collaboration with these countries can expand from a traditional focus on technical applications into combined education, doctrine, and policy. The thesis closes on a cautionary note, arguing that the Department of Defense needs to carefully consider how it will develop trust with foreign spacefaring militaries, with the Department of Commerce likely to assume responsibility for the foreign engagement associated with the United States' space situational awareness data-sharing agreements by 2024.

Mcgowan, Jeremy A. **"Small Satellite Sensor and Processing Analysis for Maritime Domain Awareness."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2018. https://hdl.handle.net/10945/59719

Abstract: The potential feasibility for on-board image processing on small satellites was investigated to meet rapid revisit requirements for Maritime Domain Awareness (MDA). Hardware and software solutions for on-board processing were explored. Resolution requirements for use of satellite imagery to both determine the type and class of a ship were investigated. Current small satellite imaging sensor technology was discussed to meet this resolution requirement. Current unclassified ship detection and classification software developed by Space and Naval Warfare Systems Command (SPAWAR) was researched and discussed as a possible solution and also to gain an understanding of current image processing software capabilities and shortcomings for identifying and classifying ships. Consequently, the state of the art for satellite digital image processing was investigated along with computer vision and machine learning techniques. MATLAB was used to simulate the effectiveness of current forms of these techniques on high-resolution satellite imagery for certain ship classes. Processing hardware and artificial intelligence image processing algorithms for detecting and classifying ships within images were found not yet suited to full automation and hosting on a small satellite. Further research and development efforts are needed in this area.

Swintek, Philip C. **"Critical Vulnerabilities in the Space Domain: Using Nanosatellites as an Alternative to Traditional Satellite Architectures."** Master's thesis - Defense Analysis (Irregular Warfare) & Space Systems Operations, Naval Postgraduate School, 2018. https://hdl.handle.net/10945/59600

Abstract: Today, the U.S. military relies upon space-based technology for a myriad of functions from precision navigation to satellite communication. Satellites greatly enable the modern American military and particularly empower special operations forces across the globe, supporting decentralized and geographically disparate operations. However, the U.S. is highly reliant upon this technology and thus increasingly vulnerable with potential adversaries undoubtedly possessing, or at least cultivating, the ability to attack America's space-based infrastructure. As a safeguard against such vulnerabilities, nanosatellites, cube satellites (CubeSats), and other small satellites are a low-cost and expedient solution to build redundancy and resiliency, offering unique options as an alternative to traditional satellite systems. To support this hypothesis, this thesis provides such an alternative: A Software Assisted VHF Information Overhead Relay-CubeSat (SAVIOR-Cube). SAVIOR-Cube is a software-defined radio (SDR) payload operating as a very high frequency (VHF) relay via a nanosatellite in low Earth orbit. This thesis demonstrates the depth of the problem a payload such as SAVIOR-Cube could solve, the applicability of nanosatellite solutions to U.S. forces today, and the results of extensive testing, culminating with a proof of concept high-altitude balloon flight. Nanosatellites are a viable alternative to traditional space-based infrastructure—a solution to a critical vulnerability.

Walker, III, Alan A. **"Implementation of the Fast Fourier Transform Onboard CFTP-7 Space Experiment."** Master's thesis - Electrical Engineering, Naval Postgraduate School, 2018.
https://hdl.handle.net/10945/59613
Abstract: A satellite to be used as a testbed for experiments such as the Configurable Fault Tolerant Processor (CFTP) was designed at the Naval Postgraduate School. This processor consists of a Field Programmable Gate Array (FPGA), which may be reprogrammed by receiving a signal from a source external to the satellite. Experimentation of a high-speed pipelined and fault tolerant Fast Fourier Transform (FFT) was conducted for use within the CFTP. In this thesis, we detail the development and testing of a high-speed pipelined FFT in which fault tolerance can be applied at a later opportunity. Xilinx Vivado ISE® was utilized to synthesize behavioral Verilog to program an FPGA. Xilinx Vivado ISE's® simulation suite produced waveforms to demonstrate functionality. Launch of CFTP is planned for FY18 aboard NPSat-1.

Writt, Andrea J. **"Optimization of CubeSat Ground Stations for Increased Satellite Numbers."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2018.
https://hdl.handle.net/10945/59624
Abstract: This thesis contributes to the growing body of research concerned with the issue of the increasing numbers of government small satellites (SmallSats) and the limited number of ground stations available to support these missions. To understand this "many satellite, few ground station" problem, a Monte Carlo simulation is used to identify the point at which a single ground station is expected to be overwhelmed, specifically looking at the case of the Mobile CubeSat Command and Control (MC3) ground station at the Naval Postgraduate School (NPS). Ground station saturation is defined in terms of data downlink requirements and the increasing number of conflicting passes as the number of SmallSats grows. An assessment of when one ground station becomes insufficient for a growing number of SmallSats is the result. The MATLAB software tools created to generate these scenarios are generic and can be used to extend this work to investigate other scenarios of SmallSats and multiple ground stations.

Yungbluth, III, John C. **"Small Satellite Swarm Theory for Sparse Aperture Radar Applications."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2018.
https://hdl.handle.net/10945/61306
Abstract: In the next few years, the Space Systems Academic Group (SSAG) and the Small Satellite Laboratory at the Naval Postgraduate School (NPS) may begin work on a small satellite swarm constellation. This thesis introduces flight operations concepts for small satellite formations conducting sparse aperture radar missions to inform decision makers at NPS of possible flight operations options. An orbital modeling program called Systems Tool Kit was used to simulate combinations of flight patterns and orbits, including a pendulum and a helix inline hybrid model, and a cartwheel hybrid model. The MATLAB software package was used to plot the simulated orbits, calculating the flight formation stability, and for calculating the relative effects of sensor separation on the system resolution. Findings include a stable dispersion pattern for the satellites to conduct their mission and an ability to maintain safe, collision-free flight operations.

2017

Alshaya, Faisal S. **"Leveraging the NPS Femto Satellite for Alternative Satellite Communication Networks."** Master's thesis - Systems Technology (Command, Control, & Communications), Naval Postgraduate School, 2017.
https://hdl.handle.net/10945/56121
Abstract: Femto satellites may provide solutions for the U.S. military in different areas. Specifically, these satellites may offer an effective and affordable alternative approach when the military faces a denial of access to primary space assets. Their low cost allows for the rapid simultaneous deployment of multiple Femto satellites, which contributes to rapid recovery from a denial situation. This thesis focuses on the communication application of Femto satellites by investigating the ability of the first and next generations of Naval Postgraduate School Femto Satellites (NPSFS) to provide a low data throughput. We modeled the first generation of NPSFS as a space-based network using System Tool Kit with QualNet (STK/QualNet) software. For the next generation of NPSFS, we conducted an experiment using Intel Arduino 101 to control the Iridium 9602 Modem, also known as the RockBlock MK2, to test the possibility of sending a text file from one terminal to another. The results confirmed the power limitation associated with Femto satellites, which reduces their suitability for implementation as a viable space network. Nevertheless, the results showed that providing a low data throughput is feasible. Finally, we suggest ways to improve the next-generation NPSFS.

Banuelos, Cervando A. **"Development of Information Assurance Protocol for Low Bandwidth Nanosatellite Communications."** Master's thesis - Computer Science, Naval Postgraduate School, 2017.
https://hdl.handle.net/10945/56101
Abstract: Nanosatellites provide a light, efficient, and cost-effective way for research institutions to carry out experiments in low Earth orbit. These satellites frequently use the ultra-high and very high frequency bands to transfer their data to the ground stations, and oftentimes will use internet protocol and Transmission Control Protocol as a standard for communication to ensure the arrival and integrity of the data transmitted. Due to bandwidth limitations and signal noise, these connection-based protocols end up accruing a large data bandwidth cost in headers and retransmissions. Furthermore, due to connection unreliability, encryption and integrity checks present a challenge. The aim of this thesis is to develop a software-based low-bandwidth reliable network protocol that can support a cryptographic system for encrypted communications using commercial off-the-shelf components. This protocol reduces the data overhead, retains the retransmission functionality and integrates support for a cryptographic system. This thesis develops the encryption mechanism, assesses its resilience to error propagation, and develops the protocol to work over a simulated network. The result of the study is a proof of concept that the protocol design is feasible, applicable, and could be used as a communication standard in future projects.

McIver, Charles A. **"Spectral LiDAR Analysis and Terrain Classification in a Semi-Urban Environment."** Master's thesis - Space Systems Operations & Remote Sensing Intelligence, Naval Postgraduate School, 2017.
https://hdl.handle.net/10945/53017
Abstract: Remote-sensing analysis is conducted for the Naval Postgraduate School campus, containing buildings, impervious surfaces (asphalt and concrete), natural ground, and vegetation. Data is from the Optech Titan, providing three-wavelength laser data (532, 1064, and 1550 nm) at 10–15 points/m2. Analysis techniques for laser-scanner (LiDAR) data traditionally use only x, y, z coordinate information. The traditional approach is used to initialize the classification process into broad-spatial classes (unclassified, ground, vegetation, and buildings). Spectral analysis contributes a unique approach to the classification process. Tools and techniques designed for multispectral imagery are adapted to the LiDAR analysis herein. ENVI's N-Dimensional Visualizer is employed to develop training sets for supervised

classification techniques, primarily Maximum Likelihood. Unsupervised classification for the combined spatial/spectral data is accomplished using a K-means classifier for comparison. The campus is classified into 10 and 16 classes, compared to the four from traditional methods. Addition of the spectral component improves the discrimination among impervious surfaces, other ground elements, and building materials. Maximum Likelihood demonstrates 75% overall classification accuracy, with grass (99.9%), turf (95%), asphalt shingles (94%), light-building concrete (89%), sand (88%), shrubs (85%), asphalt (84%), trees (80%), and clay-tile shingles (77%). Post-process filtering by number of returns increases overall accuracy to 82%.

Smoke, Jarrad A. **"Comparison of Polarimetric Cameras."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2017.
https://hdl.handle.net/10945/53050
Abstract: This thesis is an analysis and comparison of two polarimetric imaging cameras. Previous thesis work utilizing the Salsa Bossa Nova polarimetric camera provided modestly successful results in the application of the camera in determining operational uses of polarization in the field of remote sensing. The goal of this thesis is to compare polarimetric data between two cameras designs and analyze the capabilities of a newly obtained polarimetric camera from Fluxdata. The Fluxdata and Salsa cameras utilize two different techniques to capture polarized light. The Salsa uses a Division of Time Polarimeter (DoTP), which is sensitive to movement, and the Fluxdata camera uses a Division of Amplitude Polarimeter (DoAmP), which is designed to split the incoming light without errors from scene movement. The assumption is that the new Fluxdata camera will be able to capture higher-quality polarization data that can be used in classifying objects in moving scenes. The results of the study confirmed both cameras' display correct polarization signatures and the movement of objects is not affected by the Fluxdata. The Fluxdata displays more detailed polarization signatures, but still suffers from registration errors that are inherent to the focal plane alignment of the DoAmP design.

Wildt, Christopher F. **"Accuracy in Orbital Propagation: A Comparison of Predictive Software Models."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2017.
https://hdl.handle.net/10945/55555
Abstract: Current analytical satellite vulnerability planning in the U.S. Space Surveillance System is reliant on two orbital propagators, PPT3 and SGP4, both of which have a foundation in similar theory. Since their first operational use, both propagators have incorporated updated theory and mathematical techniques to model additional forces in the space environment, causing their calculation methods to diverge over time. The aggregate effects of these diverging mathematical techniques cause calculation differences for perturbations of an orbit over time, resulting in differences in future predicted positions from PPT3 and SGP4, as well as differences in their accuracy. The atmospheric model within each propagator is determined to be the most effective component of each propagator to test, as the theoretical atmospheric drag calculation methods of PPT3 and SGP4 differ greatly. PPT3 and SGP4 both perform well within the expected accuracy limits inherent with analytical models, with neither propagator demonstrating an accuracy rate decay that was significantly better or worse than the other. Compared to ground truth observations, both propagators demonstrate decreased accuracy for satellites under greater effects from atmospheric drag, i.e., satellites that are closer to the Earth. Satellite vulnerability planning with these propagators should therefore utilize the most current TLE data available to avoid accuracy errors.

2016

Connolly, James P. **"Technique for Geolocation of EMI Emitters by O3b Satellites."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2016.
https://hdl.handle.net/10945/49440
Abstract: This thesis investigates how and to what effectiveness the O3b commercial satellite constellation could be used for geolocation of Ka-band EMI sources in support of the DOD. Review of commonly used geolocation techniques for suitability and comparison of those with the O3b constellation characteristics shows that a new method of geolocation is necessary and possible. A method using the Doppler effect with frequency data from a single antenna was then created that is compatible with O3b. This method uses the received frequency of the jammer over time to detect the base frequency, and then compares the received frequency to that of simulated emitters at known locations in order to provide a geolocation for EMI emitters. This was modeled to be accurate within 16 km throughout O3b's service area. This level of accuracy would provide the ability to mitigate the interference or decrease a search area for assets with higher capabilities in order to increase their efficiency of tasking/use. This method is of further benefit to the DOD due to its potential to be low cost, be maintained as an organic capability by the units, and decrease the time necessary to reach a conclusion when working through the Joint Spectrum Interference Resolution process.

Drew, Jerry V. **"Evolved Design, Integration, and Test of a Modular, Multi-Link, Spacecraft-Based Robotic Manipulator."** Master's thesis - Astronautical Engineering, Naval Postgraduate School, 2016.
https://hdl.handle.net/10945/49446
Abstract: This thesis reports on the evolved design, test, and integration of a robotic manipulator consisting of multiple modular links, which enable the reconfiguration of the manipulator system for differing mission requirements without constructing unique hardware for each experimental campaign. The evolved design replaced custom components with commercial components to improve performance, standardize hardware, and reduce assembly time. Additional links were constructed and assembled into a four-link manipulator capable of moving its end-effector without imparting motion to the base spacecraft. Each joint can be controlled independently and provides unique telemetry data via Wi-Fi. A mathematical model of the system was implemented, and the kinematic and dynamic behaviors calibrated, resulting in confirmation of the validity of the modular link manipulator concept. A software code based on this model, the Spacecraft Robotics Toolkit (SPART), was published as an open-source kinematics/dynamics and control framework for use by the spacecraft robotics community. Future research will investigate further upgrades, manipulator control and use in operational scenarios.

Duque, Rafael A. **"Geostationary Collocation: Case Studies for Optimal Maneuvers."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2016.
https://hdl.handle.net/10945/48511
Abstract: Satellite collocation is not a new topic in the space community. The geostationary belt is considered a natural resource, and as time goes by, the physical spaces for geostationary satellites will run out. The Brazilian Air Force plans to collocate its satellite with another two satellites, and this thesis seeks the most efficient method in terms of fuel optimization and operational aspects. A Systems Tool Kit (STK) software simulation was developed that included various longitude collocation schemes for the Brazilian scenario. The STK simulations showed that a relatively low eccentricity can be achieved with a sun-pointing perigee strategy but that fuel utilization was fairly the same in all of the scenarios. The key takeaway is the operational aspect that relates to how often a maneuver is performed regarding thrusters utilization, minimizing failure risks, and operations workload. To make a solid decision on which strategy to take, other factors must be taken into account and will be commented upon in this work.

Griggs, Martin J. **"Experimental Test Rig for Optimal Control of Flexible Space Robotic Arms."** Master's thesis - Astronautical Engineering, Naval Postgraduate School, 2016.
https://hdl.handle.net/10945/51706
Abstract: The goal of this thesis was to build an experimental test rig for demonstrations on flexible space systems control. Specifically, an air-bearing test bed incorporated a two-degree of freedom (2DOF) rigid robotic arm and an appendage with flexible joints to test the effects of movement of the robotic arm on the appendage. The two-link, 2DOF rigid robotic arm can be used to simulate a moving space antenna or other movable appendages. Optimal trajectories of the two-link arm to simulate a conventional antenna slewing maneuver were investigated, to illustrate the type of flexible motion that may be produced in the laboratory. An iterative process was used to refine the test bed design and the experimental workflow. Three concepts incorporated various strategies to design a robust flexible link. Inertia measurement units (IMU), a central processor for data analysis, power distribution, and robotics software, are all integrated as part of the test bed design. A single link arm with a torsional, helical spring at the base was finalized to investigate the effects of coupling due to movement of the rigid two-link arm. The torsional spring allowed the vibrating arm to displace sufficiently to have a high signal-to-noise ratio compared to earlier concepts in which IMU noise dominated the response. The test bed was designed to accommodate further testing that may require increased loading due to, for example, the incorporation of reaction wheels or additional instrumentation.

Hartmann, David R. **"Power Savings through Onboard Orbit Propagation for Small Satellites like NPSAT1."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2016.
https://hdl.handle.net/10945/48532
Abstract: The thesis investigates the feasibility of duty cycling the GPS receiver onboard small satellites like NPSAT1 in order to repurpose power savings in ways that would better serve the satellite's mission. Orbital propagation software run on onboard computer hardware produces accurate ephemeris data over short periods without continued GPS input. Longer periods relying on propagator ephemeris translate to greater power savings, but it also means increasing positional error. In order to better define the trade space between time and error of common propagators, Systems Tool Kit software was used to test the accuracy of the Two-Body and Simplified General Perturbations-4 propagators over time against positions measured by the Joint Space Operations Center. Two-Body propagators' error response varies as a function of altitude and inclination, with the worst case requiring GPS updates up to twice an orbit. Simplified General Perturbations-4 propagators' error depends strongly on the accuracy of the B* drag term, but is still sufficiently accurate to operate a day or more without a GPS update. Savings in the GPS power budget were found to exceed 96% and 99% for Two-Body and Simplified General Perturbations-4 propagators, respectively, and should be considered for use in future satellites.

Jackson, Andrew S. **"Implementation of the Configurable Fault Tolerant System Experiment on NPSAT-1."** Master's thesis - Electrical Engineering, Naval Postgraduate School, 2016.
https://hdl.handle.net/10945/48536
Abstract: Space is a harsh environment, full of high-energy radiation that can cause single-event effects (SEE) in orbiting satellites. Some of these effects, such as single-event upsets and single-event functional interrupts, occur when ionizing radiation causes the logical value in a memory element to change and are detectable and correctable through various error mitigation techniques. In this thesis, we develop and implement a hardware solution to combat these SEE for deployment as an experimental module on Naval Postgraduate School Satellite 1 (NPSAT-1). Based on the relatively benign orbit of NPSAT-1, industrial-grade, commercial-off-the-shelf components that have shown tolerance to radiation were selected to keep costs low. The primary source of mitigation relies on a globally triple-modular redundant microprocessor system instantiated inside of a XILINX Kintex-7 field-programmable gate array. The system consists of an open-source microprocessor without interlocked pipeline stages (MIPS) based processor softcore, a cached memory structure capable of accessing

double-data rate type three and secure digital card memories, an interface to the main satellite bus, and XILINX's soft error mitigation softcore. The hardware was tested both in and out of the system and verified to work on the ground with faults injected. Other techniques to mitigate errors due to SEE, such as memory scrubbing, are intended to be added before launch.

Lin, Jianwen. **"Optimization of Inter-Cubesat Communication Links."** Master's thesis - Electrical Engineering, Naval Postgraduate School, 2016. https://hdl.handle.net/10945/70982
Abstract: Cubesat constellations may become the next generation of communication backbone architecture to provide future worldwide communication services. In this thesis, we investigate the feasibility of deploying Cubesat constellations with inter-satellite links (ISL) for the delivery of continuous global communication. Cubesat constellation designs for various mission scenarios are proposed and verified using a simulation toolkit commonly used by space engineers. Link optimization to improve the overall theoretical data rate is also discussed. The results obtained affirm that a Cubesat constellation at an orbital height of 450 km can achieve a data rate of 11.46 kbps and requires the least number of satellites in the constellation. We ascertained that using ISL as the communication backbone in a network architecture, complete with space and globally distributed ground nodes, is achievable. In the near future, there is a high potential for the implementation of ISL with optical communication links, whereby there is assurance of a significantly higher data rate and lower power requirements.

Monk, Colin S. **"Closed-Loop Optimal Control Implementations for Space Applications."** Master's thesis - Astronautical Engineering, Naval Postgraduate School, 2016.
https://hdl.handle.net/10945/51586
Abstract: This thesis explores concepts for a closed-loop optimal control implementation of minimum-time attitude maneuvers of spacecraft. The most common implementation of optimal control solutions is via open-loop commands. However, ignorance of the true system parameters can undermine the open-loop optimal control solution. While traditional closed-loop control methods can compensate for significant levels of uncertainty, this comes at the cost of optimality. This work focuses on optimization of eigenaxis maneuvers, but the concepts are not limited to this constraint. The study begins with an examination of candidate control architectures, weighing the advantages of various closed-loop feedback architectures. A control architecture consisting of a traditional proportional-derivative (or quaternion error) feedback loop and a feed-forward control torque signal is deemed to have the best performance and is then selected for further study. Next, through the analyses of a series of optimal control problems, several real-time optimal control algorithms are developed that continuously adapt to feedback on the system's actual states throughout the maneuver. These algorithms demonstrate significant performance improvements over conventional open-loop implementations, most notably shorter overall maneuver times. The results of this work, therefore, provide an algorithmic enhancement of spacecraft agility.

Olson, Dennis R. **"Low-Impact Space Weather Sensors and the U.S. National Security Spacecraft."** Master's thesis - Systems Engineering Management, Naval Postgraduate School, 2016.
https://hdl.handle.net/10945/50461
Abstract: Incorporating inexpensive low-impact targeted surface charging (plasma) and total ionizing dose (radiation) sensors onto national security spacecraft to monitor real-time environments local to each spacecraft will close a gap in the U.S. space weather observation network. Evaluation of the current space weather monitoring architecture identified key stakeholders and their needs, as well as a gap in targeted data. This paper outlines a solution to improve national security spacecraft anomaly resolution and resiliency while decreasing system life-cycle cost. A technical assessment of available products found that low-cost, low-impact spacecraft charging and radiation sensors exist that meet stakeholder needs. However, upon evaluating the acquisition process, weaknesses in the Joint Capabilities Integration and Development System (JCIDS) prevented the stakeholder's requirements being met. Physical modifications essential for the current space weather observation network to meet the

stakeholder's needs were identified in an IDEF0 model that represented the functional decomposition for integrated and proliferated targeted sensors using ViTech© CORE system architecting software. A risk assessment for sensor integration during each phase of the acquisition process resulted in a recommendation for national security space enterprise leadership to bypass the JCIDS process and require all national security space systems integrate low-impact space weather sensors prior to Milestone-C.

Ordonez, Michael M. **"Developing and Applying Synthesis Models of Emerging Space Systems."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2016.
https://hdl.handle.net/10945/48576
Abstract: The Department of Defense's (DOD) large satellites provide robust capabilities, but they are ill designed to combat emerging threats and concerns like anti-satellite weapons and a shrinking defense budget. Small satellites are a potential solution to this challenge, but the technology is too nascent for the DOD to deploy. This thesis addressed the DOD's need for further research on small satellites by providing a set of decision support tools that enables the exploration of small satellite physical trade-offs early in the conceptual design phase of the DOD space acquisition process. Early phases of the systems engineering process were used to identify DOD small satellite requirements and key input factors and output responses that drove meta-model development through the use of model-based systems engineering. Microsoft Excel and JMP software were employed to build synthesis models used in the decision support tools developed. The decision support tools analyzed the relationship between small satellite design inputs and outputs to provide trade space insights that can assist DOD space acquisition professionals in making better decisions in the conceptual design phase. More informed decision-making in the space acquisition process might preserve valuable DOD resources that may have otherwise been wasted.

Park, Jonathan. **"Assembly and Design Miniaturization of Floating Spacecraft Simulator and Its Magnetic Docking Interface."** Master's thesis - Mechanical Engineering, Naval Postgraduate School, 2016.
https://hdl.handle.net/10945/50464
Abstract: A detailed description of the assembly procedure of the Floating Spacecraft Simulator (FSS) has been produced for the Naval Postgraduate School's Spacecraft Robotics Laboratory. This procedure has been used to assemble an additional FSS, resulting in a total of three operational units. The second part of the research effort was devoted to the design of a miniaturized version of the FSS. Due to the finite size of the testbed, it was desirable to reduce the footprint of the FSS to increase the available space. The preliminary, yet detailed, design of the miniaturized FSS reduced its footprint by nearly 70%, from 729cm² to 225cm². The components for the design were selected from commercial-off-the-shelf sources to standardize hardware and reduce cost. A new magnetic docking interface for the miniaturized FSS has also been designed. The main features of the docking interface include an electromagnet for docking and undocking, a spring-loaded connector, and an air connection used to transfer air. Future research will build a prototype of the miniaturized simulator and its docking interface, test its capabilities, and apply upgrades as new and improved components become available.

Polat, Halis C. **"Prototype Design and Mission Analysis for a Small Satellite Exploiting Environmental Disturbances for Attitude Stabilization."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2016.
https://hdl.handle.net/10945/48578
Abstract: In order to accomplish complex and sophisticated missions, small satellites, particularly CubeSat, need a robust and accurate attitude control system. Due to the mass- and volume-constrained design environment of CubeSat, conventional methods are sometimes inadequate to provide needed performance at low altitudes where environmental disturbances are high. This thesis studies exploitation of the most dominant disturbance torque at low altitudes (i.e., the residual aerodynamic torque) for stabilization and attitude control. By shifting internal masses, the distance between the center of pressure and the center of mass

is adjusted so that the aerodynamic torque can be modulated as the control torque. To establish a realistic simulation environment, all launched CubeSat missions were analyzed in terms of their attitude control methodologies, sizes, altitudes and mission types. In light of the mission analysis, a prototype 3U CubeSat was designed with only commercial off-the-shelf components to check the practicality and feasibility of the method. The Linear Quadratic Regulator control method with gain scheduling was used to stabilize and control the attitude in a high-fidelity simulation environment. In simulations, the method stabilized the CubeSat and maintained the desired attitude under varying conditions such as initial angular velocity and displacement, orbit altitude and inclination, shifting mass fraction and CubeSat alignment and size.

Rarick, Douglas A. **"Using Monte Carlo Simulation to Improve Cargo Mass Estimates for International Space Station Commercial Resupply Flights."** Master's thesis - Systems Engineering Management, Naval Postgraduate School, 2016.
https://hdl.handle.net/10945/51601
Abstract: To resupply the International Space Station (ISS) with the items to support continuous human occupation and hardware to maintain system functionality, scientific experiments are necessary to maximize its potential as a world-class research laboratory. The transition of this function to the commercial sector under Firm Fixed-Price contracting has forced both NASA and commercial providers to adjust to make this effort successful. Improving bag-level cargo launch manifests delivered from NASA to the provider more than a year in advance is an area where significant gains can be realized by reducing, if not eliminating, costly and time-consuming analysis and/or physical rework during the launch campaign. The current process for developing these early manifests relies heavily on the experience and judgment of subject-matter experts to hand-build them for every flight. This research investigates the application of Monte Carlo simulation based on historical launch cargo data as a proof-of-concept demonstration for improving these manifest deliverables. The Monte Carlo simulation–derived manifests were checked against two dedicated ISS resupply missions, yielding promising results proving the concept. With further development, this methodology will be particularly useful in designing and implementing new cargo spacecraft.

Stroup, James C. **"NPSAT1: Assessment of Risk for Human Casualty from Atmospheric Reentry."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2016.
https://hdl.handle.net/10945/48481
Abstract: The United States government, through the Department of Defense and the National Aeronautics and Space Administration, has established clear guidelines that limit the acceptability of orbital debris fragments striking the surface of the Earth. This thesis addresses both the survivability of the soon-to-be-launched NPSAT1 satellite on its eventual reentry into the earth's atmosphere, and any potential risk to the human populace that may result. After reviewing the history of tracking objects in space, and the policies in place to limit the creation of and risk presented by orbital debris, this research analyzes each of NPSAT1's individual components for its uncontrolled reentry into the earth's atmosphere. The analysis conducted in this paper shows that although a few pieces of debris from NPSAT1 would strike the earth's surface with varying degrees of impact energy, these impacts are not expected to exceed the standards set forth by the Department of Defense.

Warrene, Crystal R. **"Optimizing Utilization of Detectors."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2016.
https://hdl.handle.net/10945/48493
This work seeks to increase the expected intelligence value collected by optimizing the time on multiple tasks. The purpose of this thesis is to provide a quantifiable process to determine how much time should be allocated to each task sharing the same asset. This optimized expected time allocation is calculated by numerical analysis and Monte Carlo simulation. Numerical analysis determines the expectation by involving an integral and a joint probability density function for a range of rates. In this case, rates are the historical hailing by taxi passengers. Monte Carlo simulation determines the optimum time allocation of the asset by repeatedly

running experiments to approximate the expectation of the random variables. This was deemed necessary to account for real-world uncertainties as applied to a taxi scenario. The taxi variables consist of hail rates of the passengers, the fare amount for the task, and how much time to pursue said fare. Accounting for the uncertainty in the hail rates was exhibited by using ranges and not given values. The relationship the rates of hails for the taxi from two passengers and the fare values gathered is important to utilizing the taxi to maximize the total fare collected.

2015

Chiew, Jingyi. **"Modelling of Picosatellite Constellation-Based Network and Effects on Quality of Service."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2015. https://hdl.handle.net/10945/45168

Abstract: The military applications for miniature, low-cost satellites that could be quickly launched to provide ad-hoc tactical networks have risen in recent years. Currently, the smallest practical variant of these miniaturized satellites is known as the picosatellite. In order to evaluate the performance of the picosatellite constellation-based network, a model that can accurately simulate the orbital physics of the constellation as well as the satellite-to-ground communication links and data traffic is necessary. The focus of this thesis was to build such a model using commercially available software and assess the effects of orbital geometries on the performance of the picosatellite constellation-based network. The research revealed that orbital planes that were inclined near the latitude of the area of interest could provide better coverage. In addition, when the satellites were spaced farther apart in the orbital plane the constellation access times were also extended. This was at a cost, however, as the link quality could be compromised. The model that was created for this research could be integrated into the Naval Postgraduate School Tactical Network Topology testbed environment to study the extension of tactical networks to orbit and allow the modelling of picosatellite architectures applied to different maritime and inland missions.

Colvin, Brandon J. **"Benefits of a Space-Based Group System Architecture."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2015. https://hdl.handle.net/10945/45828

Abstract: The volatility in today's economics has resulted in government attempts to reduce cost while maintaining performance. One of the elements examined by the Defense Advanced Research Projects Agency was the idea of fractionating a current monolithic satellite system into several smaller, space-based group (SBG) satellites. This architecture would allow for multiple, smaller, and less expensive satellites to work together to accomplish the several missions. This study focused on research and analysis of the system FireSat. The analysis removed the ground communications suite from the sensor platform. A Microsoft Excel spreadsheet was used to develop the resulting cost relation for the sensor-only satellite. Using assumptions provided by that analysis, three additional systems, currently in operation, were examined for cost savings if placed into the SBG. The Tracking and Data Relay Satellite was used as a basis for cost of a communications satellite. The cost analysis resulted in an estimated $52 million FY15 to the space segments alone. Additional research is required to determine cost savings within the full architecture and develop a risk-cost analysis to determine whether cost could be further reduced due to higher reliability, lower replacement cost risk, and longer lifetimes.

Garcia, David M. **"Fighting in a Contested Space Environment: Training Marines for Operations with Degraded or Denied Space-Enabled Capabilities."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2015. https://hdl.handle.net/10945/45858

Abstract: Space is an increasingly congested, contested and competitive environment. At the same time, the Marine Corps is becoming increasingly reliant on the capabilities space-based assets provide. This includes each of the space force enhancement capabilities, but particularly satellite-based voice and data communication; position, navigation, and timing information; and battlefield intelligence. Space capabilities are vulnerable to both space-based and terrestrial-based countermeasures. This study was conducted to determine the extent to which the Marine Corps educates and trains warfighters to operate in a battlefield where space-centric enabling capabilities are degraded or denied. The study surveyed the systems and capabilities on which the Marine Corps relies in order to enhance its execution of the highly dynamic range of military operations as well as the threats to those systems and capabilities. Furthermore, the study examined to what levels and extent related training and education should take place, and which venues would best host that training. Based on the analysis, this

thesis recommends leveraging internal Marine Corps expertise, increasing integration of space-related education and training into schoolhouse curricula and training exercises, and leveraging joint space expertise and resources to enhance Marine Corps readiness to excel in a contested space operational environment.

Garcia, Robert R. **"Integrating Space Systems Operations at the Marine Expeditionary Force Level."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2015.
https://hdl.handle.net/10945/45859
Abstract: The Marine Corps is the nation's expeditionary force in readiness and is ready to act in any capacity, at any time, and any place. A critical enabler to the success of the Marine Corps against technologically advanced adversaries in remote, austere environments, is the ability to effectively exploit space-based capabilities to maximize the operational effectiveness of the force. To this end, the Marine Corps has invested in a number of tactical space-trained personnel but has not yet fully begun to integrate space operations into Marine Expeditionary Force training, exercises, and deployments. This thesis reveals how dependent the Marine Corps is on space-based capabilities and reviews the current methods by which each Marine Expeditionary Force integrates space into day-to-day operations. This study finds that current progress is hindered due to a poor understanding among staff members of what space can bring to the fight, a non-standardized organizational structure within the Fires and Effects Coordination Center, the absence of uniform space training and assessment criteria, sparse equipment, and a critical lack of dedicated space-trained personnel to help plan for, train to, and exploit space-based capabilities. Recommendations are presented to mitigate these gaps and make better use of a critical capability.

Grompone, Alessio A. **"Vision-Based 3D Motion Estimation for on-Orbit Proximity Satellite Tracking and Navigation."** Master's thesis - Engineering Scicence (Electrical Engineering), Naval Postgraduate School, 2015.
https://hdl.handle.net/10945/45863
Abstract: The main challenge addressed in this work is to develop and validate an algorithm able to track and estimate the relative position and motion of on-orbit, un-modeled targets by using only passive vision. The algorithm developed is based on well-known image processing techniques. To achieve this goal, a number of different approaches were analyzed and compared to assess their performance for a satisfactory design. The code also has a modular general structure in order to be more flexible to changes during the implementation until best performance is reached. Artificially rendered high quality, animated videos of satellites in space and real footage provided by NASA have been used as a benchmark for the calibration and test of the main algorithm modules. The final purpose of this work is the validation of the algorithm through a hardware-in-the-loop ground experiment campaign. The development of the Floating Spacecraft Simulation Test-bed used in this work for the validation of the algorithm on real-time acquisition images was also documented in this thesis. The test-bed provides space-like illumination, stereovision and simulated weightlessness frictionless conditions. Insight on the validity of this approach, describing the performance demonstrated by the experiments, the limits of the algorithm and the main advantages and challenges related to possible future implementations in space applications, were provided by this research.

Kocis, Shawn M. **"Prototyping and Characterization of an Adjustable Skew Angle Single Gimbal Control Moment Gyroscope."** Master's thesis - Astronautical Engineering, Naval Postgraduate School, 2015.
https://hdl.handle.net/10945/45208
Abstract: This thesis is the second phase of development of an open architecture control moment gyroscope (CMG). The focus is on designing an adjustable skew angle single gimbal CMG frame, and integrating a previously developed momentum wheel assembly into it. The result of this phase is a fully operational CMG that can be used to retrofit the NPS Reconfigurable Satellite Autonomy Testbed (R-SAT). The open architecture design allows for both hardware and software upgrades to the R-SAT Attitude Determination and Control

System (ADCS). This capability is vitally important in order to support the development and testing of new satellite control algorithms that can be used to improve the agility and efficiency of satellite maneuvers. The CMG developed in this project is capable of delivering 7.79 Nm of output torque at the standard gimbal rate of 1 rad/s. The CMG power consumption ranges between 50W and 100W.

Konowicz, Andrew. **"Refined Orbital Architecture for Targets of Naval Interest."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2015.
https://hdl.handle.net/10945/45209
Abstract: The objective of this research is to address the feasibility of designing prograde orbits for commercial electro-optical satellites. This study explores prograde orbits (inclined less than 90°) populated by small, inexpensive but proven commercial satellites, like SkySat-1 of SkyBox Imaging Inc. The benefits of using prograde orbits are increased coverage duration and decreased revisit, or gap, times for point targets at most latitudes. Disadvantages include a reduction of high-latitude target coverage (sometimes completely), a more elaborate ground architecture, and the increased expense of populating a constellation of these satellites—to mitigate the laws of orbital mechanics—in order to achieve the desired benefits of prograde inclinations. This thesis considers orbital plane inclinations of 30°, 45°, and 60°; designs a few 24-satellite prograde constellations; and compares the performance of these newly formed constellations to the traditional sun synchronous orbit. As anticipated by the orbital mechanics, the results show that annual coverage can increase up to 6.5 times, average access increases up to 6.94 per day, and revisit time can be reduced to as low as 2.0 hours. In addition, the approximate annual life-cycle cost will likely fall beneath $0.5 billion.

Lee, Jonathan. **"Examination of the Benefits of Standardized Interfaces on Space Systems."** Master's thesis – Systems Engineering Management, Naval Postgraduate School, 2015.
https://hdl.handle.net/10945/47294
Abstract: Space systems today are highly customized systems for which standardized interfaces rarely exist. A majority of the cost can be attributed to nonrecurring engineering costs, since these systems are redesigned each time a space system is procured. As new space systems are developed, the usage of standardized interface can prove to be highly advantageous. The objective of the thesis is to identify key interfaces that can be standardized, and to determine whether the implementation of standardized interfaces on space systems can provide any added benefits such as cost savings, schedule reductions, and a rapid replenishment capability if a system was lost. A satellite functional analysis was performed using IDEF0 models, which indicated that multiple interfaces within each subsystem can be standardized. The biggest return on investment in terms of interface standardization would come from the Command and Data Handling and Electrical Power subsystem, since each component onboard will require, at a minimum, a single data and power interface. As a result of utilizing a standard interface, cost savings can be realized through efficiencies in design and manufacturing, and allow for a rapid replenishment capability for any systems that are lost due to any type of failure. The research concludes with recommendations for standardization by subsystem and function, based on the IDEF0 analysis.

McMahan, Michael T. **"Metamaterial Absorbers for Microwave Detection."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2015.
https://hdl.handle.net/10945/45904
Abstract: The development of high-power microwave weapons and dependence on electronics in modern weapon systems presents a high-power microwave weapons threat in future military conflicts. This study experimentally determines the absorption characteristics of simple metamaterial devices to potentially be used as protection and identification mechanisms, constructed through standard printed circuit board manufacturing processes, in the microwave region. Experimental results and analysis techniques are presented confirming absorption peaks in the anticipated microwave frequency range. The experimental results are compared to a finite-element model of these metamaterials confirming the ability to accurately model and predict absorption characteristics of similar metamaterial structures. Utilization of

the absorption characteristics of these types of metamaterial structures to develop a microwave detector and/or equipment shielding is discussed. Several applications for such type of a detector are presented.

Ochs, Adam J. **"Use of Commercial Imagery Capabilities in Support of Maritime Domain Awareness."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2015. https://hdl.handle.net/10945/45917
Abstract: Maritime domain awareness (MDA) is a concern for all maritime countries. To know when ships are approaching their shores and what threats and hazards are forthcoming, MDA is imperative for protecting the homeland and its citizens. As technology has improved in the world of commercial satellite imagery, those who perform MDA have realized they can utilize these capabilities to improve their common operational picture. As satellites continue to improve, it is more feasible to utilize their products within operations centers at the operational and even tactical level. With the added benefit that this imagery is unclassified and sharable, and with the United States' desire for coalitions and sharing with partners, commercial satellite imagery is moving into the forethought of many decision makers. This research focuses on current operating procedures for MDA, the capabilities and limitations of today's commercial imaging satellites, and what ground stations are available to assist in the use of combatant commander-controlled tasking. Two major demonstrations of the use of commercial satellite imagery for MDA in this thesis provide lessons learned to be applied to future architectures and ways forward.

Perry, Derick I. L. **"Quality Initiatives in the Commercial Development of Reusable Launch Vehicles."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2015. https://hdl.handle.net/10945/45240
Abstract: This thesis examines positive tools and techniques accessible and helpful to improving quality of the Reusable Launch Vehicle (RLV). Over the last three decades, NASA has directly been involved in developing modern and technologically improved RLVs. The technologies were projected to facilitate cheaper access to orbital space, as evidenced by its past X-programs and space launch initiatives. Different private firms have attempted and are still attempting to develop new RLVs for orbital space applications. The large development expenses of these kinds of systems, coupled with the downturn of the Low Earth Orbit market, have made development of RLVs, in particular by the commercial sector, increasingly difficult. For these reasons, most commercial space transportation firms have shifted their focus toward suborbital market opportunities, where the technical challenges are lower and market entry is less expensive. This thesis identifies techniques within Lean Aerospace Initiative that are employed by market players today and also best suited for the RLV effort. Additionally, this thesis provides a historical perspective of both RLV development efforts within the government and industry, as well as origins of modern quality teachings to establish a universally accepted foundation of knowledge, upon which further examination can be based.

Thomas, Judson J. C. **"Terrain Classification Using Multi-Wavelength LiDAR Data."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2015. https://hdl.handle.net/10945/47337
Abstract: With the arrival of Optech's Titan multispectral LiDAR sensor, it is now possible to simultaneously collect three different wavelengths of LiDAR data. Much of the work performed on multispectral LiDAR data involves gridding the point cloud to create Digital Elevation Models and multispectral image cubes. Gridding and raster analysis can have negative implications with respect to LiDAR data integrity and resolution. Presented here is a method of attributing the Titan LiDAR point cloud with the spectral information of all three lasers and the potential improvement of performing all analysis within the point cloud. Data from the Optech Titan are analyzed for purposes of terrain classification, adding the spectral component to the LiDAR data point cloud analysis. The approach used here combines the three spectral sensors into one point cloud, integrating the intensity information from the 3 sensors. Nearest-neighbor sorting techniques are used to create the merged point cloud. Standard LiDAR and spectral classification techniques are then applied. The ENVI spectral tool n-Dimensional Visualizer is

used to extract spectral classes from the data, which can then be applied using supervised classification functions. The Maximum Likelihood classifier provided consistent results demonstrating effective terrain classification for as many as eleven classes.

Thomas, Matthew J. **"Conjunction of Photovoltaic and Thermophotovoltaic Power Production in Spacecraft Power Systems."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2015.
https://hdl.handle.net/10945/47338
Abstract: 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 (RTG)—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.

2014

Alcaide, Sarah M. **"Mobile CubeSat Command and Control (MC3) 3-Meter Dish Calibration and Capabilities."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2014. https://hdl.handle.net/10945/42572

Abstract: The Mobile CubeSat Command and Control (MC3) architecture is a growing network of ground stations that spans the United States of America. It was designed to support the National Reconnaissance Office's Experimental CubeSat Program. Each node was originally designed to communicate via UHF and S-band frequencies using Yagi antenna only. The MC3 ground station at the Naval Postgraduate School has recently incorporated a 3-meter S-band dish. This thesis documents the calibration and capabilities of the new S-band dish. It also investigates the possibility of using the antenna outside of its normal operating range. In particular, the idea of using an S-band, 3-meter dish to receive UHF band signals was tested by designing a UHF signal feed optimized for 915 MHz and used to listen to a UHF source deployed on a high altitude balloon at near orbital distances. In addition, this document discusses the integration of a dish system into current and future MC3 ground stations.

Arledge, Richard K. **"Implementation of Optimal Controls Using Conventional Control Systems."** Master's thesis - Astronautical Engineering, Naval Postgraduate School, 2014. https://hdl.handle.net/10945/49798

Abstract: This thesis investigates the implementation of optimal control solutions for positioning spacecraft antenna using conventional techniques. Conventional maneuvers consider each axis independently and may include artificial limits that reduce the efficiency of the system. These methods allow simple, but generally suboptimal, maneuver design. Multi-body dynamic systems do, however, exhibit coupling effects that can be advantageous for enhancing motion planning. Including coupling effects in the model can reduce energy needed to implement a slew maneuver. For example, previous work demonstrated that optimal control solutions can reduce required slew time for spacecraft antenna maneuvers. This work explores the utility of implementing such optimal trajectories as reference maneuvers using current control schemes. Development and validation of the approach is explored using systems of increasing dynamic complexity. Two methods to match given optimal control profiles using existing control logic were developed and compared against current practice. The developed methods were applied to the results for a double gimbal model and the Tracking Data Relay Satellite. The developed approach allows optimal trajectories to be successfully matched to within 2% position error along the trajectory using less than four conventional maneuvers. These results thus provide a simplified approach for implanting optimal slew maneuvers.

Argenziano, Matthew R. **"Optimal Attitude Maneuvers for the Kepler K2 Mission."** Master's thesis - Astronautical Engineering, Naval Postgraduate School, 2014. https://hdl.handle.net/10945/70976

Abstract: The Kepler satellite was designed to detect stars with planets capable of supporting life. After completing its primary mission, two of the satellite's four reaction wheels failed, severely degrading the spacecraft attitude control system. In order to continue providing useful data to the scientific community, NASA has arranged a new mission for the Kepler satellite known as the K2 mission. The K2 mission currently uses a hybrid control approach for rotating the satellite that relies on thrusters for augmenting the authority of the remaining wheels. This thesis explores the application of optimal control for minimizing fuel consumption in support of the K2 mission. Such an approach is useful not only for momentum management during pointing but also for large angle slews needed to support non-science operation. Reducing fuel consumption will further extend the life of the K2 mission. Optimal control was shown in this thesis to reduce fuel consumption by as much as 28 percent during momentum management and 30 percent for large angle maneuvers. The results of this thesis are also applicable to other missions where it is desired to operate an underactuated spacecraft in the most fuel-efficient manner possible.

Connett, Brian. **"Resilient and Fractionated Cyber Physical System."** Master's thesis - Space Operations, Naval Postgraduate School, 2014.
https://hdl.handle.net/10945/43894
Abstract: Reliance on aging monolithic overhead physical systems with assurance of resilience is an ongoing critical discussion. The White House has issued a strategy to evolve this system of systems technology to meet growing information and knowledge needs. Fractionated Space Cyber Physical Systems is part of a novel concept emerging from a field of hyperconnected networks designed to withstand risk and address aforementioned needs. The transition from a monolithic design into alternative resilient designs will better reflect the utility of a system to the commander. Resilience is a characteristic meant to assure performance even within a higher probability of risk. Resilience encourages availability regardless of the perceived threat in the increasingly dynamic environment. Traditional systems incorporate the sub-systems required to deliver the common operational picture. Reduction of those integrated sub-systems is unacceptable; therefore, introducing a decentralized architecture is going to carry with it the requirement of a seamless interaction despite being separated. Decentralization is a design process that allows a constellation capability to seek more nodes than what would be normally available when residing in the same payload. This is a measure of design success that enhances the evaluation of a system's capability and its ability to survive risk, its resilience.

DeMello, John E. **"Low-Cost Direct Detect Spaceborne LIDAR."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2014.
https://hdl.handle.net/10945/42606
Abstract: LIDAR has widely been used to create very accurate 3-D models for use in a wide range of commercial, governmental and nonprofit applications. This thesis identifies how recent advancements in Nd:YAG fiber lasers and InGaAs GmAPDs could be applied to space-borne missions, enabling low-cost solutions that fulfill NASA's ICESat-2 and United States Geological Survey (USGS) objectives. An analysis of launch vehicles, standard spacecraft buses and payload technologies identified three potential low-cost solutions: one hosted aboard Iridium and two onboard a BCP2000 commercial bus. These systems were evaluated using NASA's mass-based and aperture-based cost models to provide a rough estimate of cost versus NASA's CALIPSO, ICESat-1 and ICESat-2 missions. Preliminary analysis shows a potential for these new technologies to outperform any previous space-based LIDAR mission. At $55M, the Iridium-hosted solution is 1/16th the cost of ICESat-2 at roughly one-third its capability. Two other solutions were estimated at $216.6M and $370.586M and provided over 3X and 10X the estimated capability of ICESat-2, respectively. Both systems are anticipated to fulfill NASA's ice sheet and vegetation objectives while delivering a return on investment of roughly $1B per year based on USGS's analysis of advanced 3-D data for the United States.

Faulkenberry, Matthew E. **"Critical Review of the Navy Space Cadre."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2014.
https://hdl.handle.net/10945/42622
Abstract: The U.S. Navy has placed doctrinal emphasis on space-based capabilities as a key enabler of naval operations since 1959. But the service has not provided the associated organizational focus necessary to develop an educated, experienced, and qualified professional space cadre. Despite this management shortcoming, the Navy remains critically reliant on capabilities provided by space-based assets and has continued to exploit these capabilities. This thesis critically reviews the current Navy Space Cadre and recent trends affecting its future. The origin of the cadre, management of its billet base, professional development of members, and future structure are examined. While the Navy Space Cadre meets minimum requirements set forth in Department of Defense and Department of the Navy directives, this study finds the effectiveness of the cadre is reduced due to a poor understanding of future requirements, an underdeveloped training and education progression, a non-standardized approach to operational unit support, and an undefined career path for cadre members. Recommendations are presented to improve the effectiveness without a wholesale restructuring of the community.

Felt, Aaron J. **"Federated Ground Station Network Model and Interface Specification."** Master's thesis - Space Systems Engineering & Computer Science, Naval Postgraduate School, 2014. https://hdl.handle.net/10945/44558
Abstract: This thesis solves the problem of a lack of a complete, simple ground station network interface standard. A federated satellite ground station network (FGN) model and computer interface are developed that extend the use of ground stations to external users across the Internet. This should allow for reuse of existing ground stations, reducing costs and complexity of space missions. An improved model describing FGNs is proposed that defines a hierarchy of the components of the network, allowing for scalability and unified interfaces, and simplifying the process of using FGN resources. This model, which we call the Improved FGN model, is used to develop security schemes that are simple but effective. Simple but effective security schemes are then developed for this Improved FGN model, along with a standardized SOFtware interface. This interface connects external users to the network in order to extend ground station hardware to remote users as well as to simplify scheduling for the resource owners in a network. Different middleware frameworks are compared, and Apache Thrift is selected as the best fit for an FGN. This interface is then described and demonstrated with a reference implementation in Python. Recommendations for future improvements of this interface standard are discussed.

Foley, April J. **"Nanosat Employment: A Theoretical CONOPS for Space Object Identification."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2014. https://hdl.handle.net/10945/42623
Abstract: Space Situational Awareness and Space Object Identification are vital to discovering and assessing space-based threats. The current ground-based mission architecture and operational concept do not provide enough detailed information on space objects to give planners and strategists a true picture of the space order of battle. This thesis looks at the possibility of using space-based assets, based on the CubeSat standard, to perform these missions to a higher level of quality. How this system would be folded into the current space systems operational concept is analyzed, as well as some recommendations for further study.

Fredrick, Brian C. **"Geolocation of Source Interference from a Single Satellite with Multiple Antennas."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2014. https://hdl.handle.net/10945/41379
Abstract: Interference of satellite communications is a frequent and ongoing concern for both DoD and civilian enterprises. Geolocation of the interfering source is an essential step in mitigating or eliminating the interference and restoring operation of the communications service. Existing techniques to locate sources of such interference are not applicable to newer satellite communications systems. This thesis offers an innovative method for locating interference that takes advantage of modern multi-antenna satellites. The location of a source of radio frequency interference can be determined by comparing the received signal strength across multiple antennas on the same satellite. The difference between signal strength'as received by the satellite antennas'can be computed and plotted as lines of position on the surface of the Earth. The intersection of two or more lines of position represents the location of the interfering transmitter. An advantage of this method is that it is completely passive and can be done in real time. The size and accuracy of the resultant geolocation area are a function of a number of different factors, including terrestrial latitude of the interfering transmitter, the accuracy of the signal strength measurement, and the geometry of the intersecting lines of position.

Helker, Joseph K. **"NPS Solar Cell Array Tester CubeSat Flight Testing and Integration."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2014.
https://hdl.handle.net/10945/43925
Abstract: 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.

Kaufman, James M. **"Automated Maneuver Design and Checkout for the Lunar Reconnaissance Orbiter."** Master's thesis - Astronautical Engineering, Naval Postgraduate School, 2014.
https://hdl.handle.net/10945/44592
Abstract: The Lunar Reconnaissance Orbiter (LRO) is a lunar surface mapping and data collection mission launched by NASA in 2009. As a mapping and imaging mission, frequent attitude maneuvering is required. The LRO currently follows a trial-and-error method to design maneuvers to prevent sensitive instruments from pointing at bright objects that may damage the equipment. Additionally, eigenaxis maneuvers are the primary method by which the attitude is controlled. In this thesis, optimal control theory is applied to provide automated maneuver design capabilities to support the LRO mission. The approach allows dynamic constraints, as well as other constraints such as occultation avoidance, to be easily incorporated into the maneuver design process. This aspect also simplifies maneuver checkout activities. The results of this thesis show that maneuvers can be designed to reorient the LRO in the presence of multiple occultation constraints. Moreover, maneuver times can be reduced up to 90 percent compared to the conventional approach. This increases the potential for efficient science data collection.

Kaushish, Vidur. **"Force Limited Vibration Testing and Subsequent Redesign of the Naval Postgraduate School CubeSat Launcher."** Master's thesis - Astronautical Engineering, Naval Postgraduate School, 2014.
https://hdl.handle.net/10945/42656
Abstract: The Naval Postgraduate School CubeSat Launcher (NPSCuL) is a five-sided structure capable of carrying up to 24 CubeSats to orbit. The vibration test environment for CubeSats flying on NPSCuL on the Atlas-V is extremely harsh, partly due to the input vibration environment from the launch vehicle itself, and partly due to amplification from the NPSCuL structure. This thesis documents the implementation of a relatively new technology, Force Limited Vibration Testing (FLVT), and the design of a stiffer structure to reduce the vibration environment for NPSCuL payloads. Most acceleration-controlled vibration tests result in significant over-test. FLVT limits shaker forces, producing more realistic tests and potentially provides relief to payloads. Additionally, increasing the stiffness of NPSCuL using an isogrid design, aimed to increase its first-fundamental frequency, could result in less displacement at higher frequencies for a given amount of input energy, possibly improving the payload vibration environment. It was found that FLVT was very successful in reducing vibration environments for NPSCuL payloads. Although redesigning NPSCuL using an isogrid design achieved the goal of increasing system stiffness, it did not reduce the vibration environment. None the less, lessons learned from the redesign process will be valuable for continuing vibration environment reduction efforts.

Krueger, Michael R. **"A Comparison of Detection and Tracking Methods as Applied to OPIR Optics."** Master's thesis - Astronautical Engineering, Naval Postgraduate School, 2014.
https://hdl.handle.net/10945/44600
Abstract: The objective of this research is to investigate and evaluate detection and tracking algorithms suitable for Overhead Persistent InfraRed (OPIR) coverage of moving ground targets. One of the largest hurdles is operating with a low signal-to-noise ratio (SNR) in a cluttered environment. The local contrast method (LCM) and principal component analysis (PCA) detection algorithms will be explored and tested while centroid and correlation tracking algorithms will be discussed.Kalman and alpha-beta filters will be compared and contrasted as viable track prediction techniques. This work will also provide a solid knowledge base for future research on the High Energy Laser (HEL) Beam Control Research Testbed that the Naval Postgraduate School is developing in partnership with Boeing Directed Energy Systems. While they are different applications, both HELs and OPIR share common detection and tracking strategies. Simulation results show that the LCM is superior to PCA. However, the best results are obtained by combining the two.Kalman and alpha-beta filters handle single targets with a constant velocity or acceleration with ease, but advanced tracking methods like the velocity matched filter to provide constraints would provide a more robust solution when performing multiple target tracking.

Leszczynski, Matthew J. **"Improving the Performance of MEMS Gyros via Redundant Measurements: Theory and Experiments."** Master's thesis - Astronautical Engineering, Naval Postgraduate School, 2014.
https://hdl.handle.net/10945/44605
Abstract: A redundant sensor array is a device composed of more than one sensor of a given type, for example an array of rate gyroscopes. Previous work has shown that redundancy can enhance the failure tolerance of the sensor suite and can also be leveraged to improve the accuracy of the measurements. This thesis further explores the possibility of improving the performance of low-cost micro-electro-mechanical (MEMS) gyroscopes using the redundancy concept. To this end, an experimental sensor array test bed is constructed that allows data from up to 12 three degrees of freedom MEMS gyroscopes to be acquired and combined under various geometric configurations. By organizing the MEMS gyroscopes in ideal geometric configurations, it is shown how the effects of sensor noise can be reduced in order to increase the precision of the measurements. Experiments using the constructed sensor array test bed show that the 1-σ sensor noise can be reduced by nearly 65 percent through the proper combination of multiple measurements using ten 3 degrees of freedom gyros. It is further observed that realizing this improvement relies, in part, upon accurate estimation of the sensor bias. This aspect motivates future work on bias estimation schemes for arrays of sensors.

Mroczek, Austin J. **"Determining the Cost Effectiveness of Nano-Satellites."** Master's thesis - Systems Engineering Management, Naval Postgraduate School, 2014.
https://hdl.handle.net/10945/43959
Abstract: Nano-satellites have grown in popularity and capability since the 1990s. Over ninety were launched into low earth orbit between November 2013 and January 2014. Various Department of Defense services and agencies, including the Department of the Navy, have funded a number of demonstration missions that are being evaluated for military utility. While nano-satellites cost significantly less than traditional space missions, they also provide less capability. A quantitative method is required to determine the cost-effectiveness of nano-satellite missions to inform naval decision-makers. This thesis develops a framework to compare the cost-effectiveness of nano-satellites. After examining different methods of quantifying small-satellite performance and cost, a generic cost-effectiveness model is developed. The model is demonstrated using two hypothetical scenarios where both nano-satellite and traditional satellite options are considered.

2013

Adams, Priscilla M. **"The Future of Human Space Exploration: Toward Cooperation or Competition?"** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2013.
https://hdl.handle.net/10945/37577
Abstract: Over the past 52 years, the world has progressed from the first man in space, to landing on the moon, to permanent human presence on manned space stations. Mankind is now poised to explore even farther. The purpose of this thesis is to analyze whether international cooperation or competition is more in the U.S. interest from the perspective of political, technological, and cost-effectiveness criteria for returning humans to the moon, Mars or an asteroid and establishing a permanent presence. The 1960s space race between the U.S. and USSR and current cooperation on the International Space Station will provide a historical basis for comparison. Countries with major space programs will be reviewed for possible partnerships in future space endeavors. This thesis concludes that the future and next steps for human spaceflight with international partners will need to begin as a coordinated and interdependent effort at the onset with the goal of habitation on the moon.

Brandt, Jason J. **"Fault-Tolerant Sequencer Using FPGA-Based Logic Designs for Space Applications."** Master's thesis - Electrical Engineering, Naval Postgraduate School, 2013.
https://hdl.handle.net/10945/38884
Abstract: The design of a device that controls the sequence and timing of deployment of CubeSats on the Naval Postgraduate Schools CubeSat Launcher (NPSCuL) is detailed in this thesis. This design is intended to be implemented on a field-programmable gate array (FPGA) installed into the NPSCuL. This configuration allows flexibility in reprogramming the launch sequence and adding additional functionality in future designs. Operating an FPGA on orbit presents unique challenges due to the radiation environment. Radiation from space cannot be shielded efficiently, so devices must be tolerant of the expected effects. The most common effect, the single-event upset can have detrimental effects on operating electronics, causing undesired changes to data. To combat this problem, fault tolerant techniques, such as triple-modular redundancy (TMR) are explored. In these methods, multiple redundant copies of the design are operated simultaneously, and the outputs are voted on by special circuits to eliminate errors. Comparisons between manual and software generated TMR methods are tested, and the design is implemented on test hardware for further verification. Finally, future research and testing is discussed to continue to ready the design for employment of the sequencer on an actual space mission.

Buehler, Matthew D. **"Replacement Capability Options for the United States Space Shuttle."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2013.
https://hdl.handle.net/10945/37590
Abstract: After having invested millions of dollars into the International Space Station (ISS) and retiring the Space Shuttle, NASA and the U.S. are in the rare position of not having an operational human space lift program to reach the ISS or any location in space. This is truly an unusual time period in the history of NASA manned spaceflight. This thesis addresses the human spaceflight, Up Mass (launch a payload into space), and Down Mass (return payload from space) capabilities of the U.S. Space Shuttle and assesses options to regain these capabilities now that the Space Shuttle is retired. The research in this thesis was done with unclassified and public-domain information and was used to evaluate and propose options for mitigating the capability gaps left by the end of the United States Space Shuttle program. No current or planned system can fulfill all the capabilities that the Space Shuttle was able to provide. However, there are current/future domestic and foreign systems that can or will address these capabilities individually.

Burniston, Matthew P. **"NROL-41 Go for Launch."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2013.
https://hdl.handle.net/10945/34637
Abstract: The current national economic situation has forced every Department of Defense program to find ways to accomplish more with fewer resources. Spacelift, as one of the most expensive government programs, has continuously been scrutinized and challenged to lower costs and work more efficiently. This thesis reviews a summarized history of events that brought the current launch community to its present state and then details the events of the NROL-41 launch campaign. NROL-41 was the most efficient launch campaign to date and a study of the work completed on the launch shows the depth of effort required to achieve mission success. Spacelift is an expensive and dangerous endeavor, but the risk of launch failures and loss of satellites is worth every penny spent to deliver mission success. This thesis provides the data to justify those costs as well as recommendations of studies that could be performed to define more appropriate places to cut spending without increasing risk.

Burwell, Alan C. **"Global Positioning System Disaster Notification Messaging Service."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2013.
https://hdl.handle.net/10945/37592
Abstract: The United States has offered free worldwide position, navigation, and timing (PNT) broadcast data through the Global Positioning System (GPS) since its 1993 initial operations capable declaration, and periodic modernization efforts have been made throughout its 20-year history. A planned modernized L5 safety of life GPS signal, combined with the current GPS-enabled device ubiquity, offers an unprecedented opportunity to embed and broadcast other non-PNT information into GPS signals and reach individuals on a global scale with information in new ways. Adequate additional bandwidth exists in the new L5 safety of life signal to embed notification information for worldwide natural and technological disasters and add a new communication medium for a possible global disaster notification system. This thesis explores the background, requirements, system design and U.S. policy of a disaster-notification enabled GPS L5 safety of life signal.

Chow, David J. **"Exploring the Feasibility of Providing Electrical Power to Remote Bases via Space-Based Solar Power Satellites."** Master's thesis - Systems Engineering Management, Naval Postgraduate School, 2013.
https://hdl.handle.net/10945/34645
Abstract: 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.

Contreras, Gregory M. **"Design and Prototyping of a Satellite Antenna Slew Testbed."** Master's thesis - Astronautical Engineering, Naval Postgraduate School, 2013.
https://hdl.handle.net/10945/38908
Abstract: The purpose of this thesis is to contribute to the development of the next generation slewing antennas for spacecraft, ground or sea systems. Current antenna slewing systems may also benefit from the results. More specifically this thesis provides a new testbed for implementing slew maneuvers in a laboratory environment. The antenna slew testbed was built with in-house manufactured parts, 3-D printed parts and commercial-off-the-shelf equipment. The approach for designing this testbed involved CAD analysis and rapid prototyping, the application of dynamic scaling and similitude concepts, and implementation of hardware and software to support experimentation of novel maneuver concepts. To illustrate this, a maneuver based on optimal control theory is implemented. The applicability of this testbed casts a wide net because of its scale size as compared to existing or future systems. Moreover, the testbed is designed in a modular form to allow a variety of different antenna systems to be represented for testing slews. These include ground, space, and shipboard antenna systems.

Cooper, Chad W. **"Enhancing Arctic Surveillance with Space-Based Radars."** Master's thesis - Systems Technology (Command, Control, & Communications), Naval Postgraduate School, 2013.
https://hdl.handle.net/10945/34649
Abstract: Recent evidence suggests that there are increasing levels of maritime activity in the Arctic Circle which requires new methods for meeting the Arctic maritime information needs of the United States and allies. Information needs are particularly acute in the most critical areas of the Arctic for the United States such as the U.S. Exclusive Economic Zone. Because the Arctic environment is inhospitable to lower atmosphere intelligence, surveillance, and reconnaissance methods with which to gather information, space-based surveillance such as synthetic aperture radar sensors are likely the best way to meet ever-increasing Arctic information needs. Modeling and Simulation was employed to determine a practical constellation design of space-based radars to remotely sense the totality of the Arctic Circle and the portion of the U.S. Exclusive Economic Zone that lies within it. Analysis of single orbital plane, Walker, and custom constellation designs determined that a constellation of three sensors strikes a balance between coverage and efficiency for Arctic surveillance. A constellation of radar sensors in sun-synchronous orbits with ascending node spacing of 50 degrees apart achieved optimality in coverage time, efficiency, and consistency in sequential 24-hour intervals.

Crews, II, Steven R. **"Increasing Slew Performance of Reaction Wheel Attitude Control Systems."** Master's thesis - Astronautical Engineering, Mechanical Engineering and Astronautical Engieer, Naval Postgraduate School, 2013.
https://hdl.handle.net/10945/37606
Abstract: This thesis explores the physical and mathematical limitations of two common attitude control systems: one based on reaction wheels and another based on control moment gyroscopes (CMGs). The dynamics are derived from first principles and control algorithms for achieving maximum reaction wheel potential are discussed. The shaped eigenaxis input is utilized to establish baseline maneuver performance. A time-optimal shaped input is introduced and implemented in a feedback setting, subject to the limitations of the Moore-Penrose pseudo-inverse control allocation. Finally, a feed-forward plus feedback controller is introduced to implement the time-optimal torque inputs directly to the reaction wheels. This obviates the need for the pseudo-inverse control allocation, and therefore exploits the total capacities of both the reaction wheel momentum envelope and torque envelope. These reaction wheel control approaches are compared with CMG performance to establish spacecraft size and slew parameters that make the use of reaction wheels a reasonable choice

Hearne, Erin T. **"Operationally Responsive Spacelift: Supporting a Seven-Day Launch Schedule."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2013.
https://hdl.handle.net/10945/34676
Abstract: In 2001, the Air Force issued AFSPC 001-01, Mission Need Statement for Operationally Responsive Spacelift, identifying the need for a responsive launch system ready to launch and reach orbit within hours of call-up to deploy space assets in support of military operations. Current range operations include months and often years of pre-launch planning and infrastructure development in order to meet launch vehicle, customer, and safety constraints. This thesis studies the Air Forces limited ability to support small satellite launches into sun-synchronous low earth orbit in response to a Tier-2 ORS request, focusing on launching from a single range with two different small payload launch vehicles and investigates the potential for making spacelift more responsive. This investigation determined that the Air Force is not currently capable of launching either vehicle type within a seven day schedule due to a variety of doctrinal, procedural, and resource challenges and restrictions. This thesis presents several suggested changes and risk mitigation options for overcoming these shortfalls in equipment, personnel, and paperwork to increase the responsiveness of spacelift in support of the Air Force and DoD launch objectives.

Jepperson, Dustin B. **"Using Model Based Systems Engineering and the Systems Modeling Language to Develop Space Mission Area Architectures."** Master's thesis - Systems Engineering Management, Naval Postgraduate School, 2013.
https://hdl.handle.net/10945/37644
Abstract: Model based systems engineering (MBSE) is explored as an alternative to the Department of Defense (DoD)s heavily document-driven processes for architecture development and acquisition management. MBSE can be employed to meet the standards set in the DoD acquisition framework. Data exchange specifications, such as the application protocol 233 (AP233), can be implemented to enable synergistic benefits to data analysis across the enterprise. Architecture development techniques, including the structured analysis and design technique and the systems modeling language (SysML), are introduced to aid in the development and assessment of space system mission area architectures, enabling rigorous mathematical analysis to support key programmatic decisions. A detailed example of the application of SysML, in conjunction with MBSE principles, is provided for the Overhead Persistent Infrared mission area, specifically the Space Based Infrared Surveillance System. A three-phase adoption approach is recommended: first identify, list, and manage the configuration of all critical program models, processes, and tools used throughout the DoD. Second, mandate a data exchange specification, such as the International Organization for Standardization (10303 AP233 standard, across the DoD space acquisition community. Finally, further standardize the implementation of MBSE practices through implementation of SysML. Heuristics for developing system architecture are provided.

Kiremitci, Huseyin. **"Satellite Constellation Optimization for Turkish Armed Forces."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2013.
https://hdl.handle.net/10945/32849
Abstract: Advancing technologies in smallsats provide remote sensing and communications capabilities achievable with a constellation of satellites at a reasonable cost to meet military needs. Like any other nation looking for a cheap but effective solution in that area, Turkey might also benefit from a replacement of its remote sensing assets. Currently Turkish Armed Forces rely on a limited number of reconnaissance aircraft and Unmanned Aerial Vehicles, which do not provide real-time or near real-time remote sensing capabilities. Near real-time remote sensing needs for the Turkish warfighter dictates Turkish Armed Forces reach that capability as soon as possible. Likewise, replacing its conventional communication radios with satellite communication devices would also fulfill warfighter needs. While current communication devices have physical limitations in Turkeys mountainous terrain and the surrounding seas, satellite communication capability would provide wider coverage and for specific frequencies might provide better resistance to jamming and interference too. For the benefit of Turkish Armed Forces communications needs, a satellite constellation must be

optimized such that effective coverage will be achieved with the least number of satellites to provide a reasonable cost. In this study, Satellite constellation optimization for the Turkish Armed Forces will be achieved by using Analytical Graphics, Inc.s Systems Tool Kit software for simulation and analysis of several possible communications and remote sensing satellite constellations covering Turkish territory and surrounding seas.

Marshall, Samuel I. **"Modtran Radiance Modeling of Multi-Angle WorldView-2 Imagery."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2013.
https://hdl.handle.net/10945/37669
Abstract: The WorldView-2 satellite, launched in 2010 by DigitalGlobe, provides researchers with the ability to collect high resolution, multi-angle, 8-band multispectral imagery. This offers a unique opportunity to investigate the reflectance propertiesincluding the bidirectional reflectance distribution functionof surfaces detected from a space-based remote sensing platform. Eight images were collected over Rio de Janeiro on January 19, 2010, at approximately 1000 local time. Solar geometry during the collect remained constant while sensor geometry ranged from approximately 10 degrees off-nadir to 60 degrees off-nadir, fore and aft. To enhance understanding and provide comparison data with the multi-angle imagery data, radiance models were generated using the Moderate Resolution Atmospheric Transfer code. General models, using surface albedos ranging from 1% to 100%, and comparison models, using properties as close as possible to that found in the imagery, were built. Using data derived from all sources, variations were readily apparent that could be attributed to the multi-angle geometry of the collect, the wavelength of the light sensed and reflectance

McLeod, Christopher W. **"Effect of Nonlinearities on Orbit Covariance Propagation."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2013.
https://hdl.handle.net/10945/37675
Abstract: This thesis will examine the effect of nonlinearities on the propagation of orbit uncertainties in order to gain insight into the accurateness of the estimation of covariance with time. Many real-world applications rely on a first-order approximation of nonlinear equations of motion for propagation of orbit uncertainty. The nonlinear effects that are ignored during the linearization process can greatly influence the accuracy of the solution. A comparative analysis of linear and nonlinear orbit uncertainty propagation is presented in order to attempt to determine when linearized uncertainty becomes non-Gaussian. An examination of performance metrics is then accomplished to compare linearly propagated uncertainty to uncertainty propagated using a second-order approximation. An attempt is then made to develop a performance metric that determines when propagated uncertainty is no longer Gaussian. The results show it is difficult to determine a clear method of defining when the linear approximated uncertainty is no longer Gaussian, but there are metrics that can be implemented given a user-defined threshold of performance.

Nakatani, Scott Y. **"Simulation of Spacecraft Damage Tolerance and Adaptive Controls."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2013.
https://hdl.handle.net/10945/34711
Abstract: In the 1950s and 1960s, the North American X-15 rocket powered aircraft was pioneering the concepts and principles that would come to define modern powered flight. Among the ground breaking ideas proposed was a system of adaptive controls, or a controller that would take into consideration the changing operational environment to deliver appropriate control to the operator. Limitations of current technology abounded, leaving the X-15 with a successful, but severely limited adaptive control system. Since then, many limitations have fallen away, allowing for the first time employment of adaptive controls on a large scale. The nature of adaptive controls, or controls for unpredictable systems, lends itself naturally to the concept of damage tolerant controls in high performing systems, such as aircraft and spacecraft. Recent technical demonstrations of damage tolerant aircraft prove the concept of adaptive controls in an operational environment. This thesis expands on the topic, discussing the application of adaptive controls to spacecraft and simulating a possible damage tolerant control implementation designed for rapid changes in inertia.

Ouch, Cheth. **"Maturity Assessment of Space Plug-and-Play Architecture."** Master's thesis - Systems Engineering Management, Naval Postgraduate School, 2013.
https://hdl.handle.net/10945/32878
Abstract: Space Plug-and-Play Architecture (SPA), as defined by the SPA subject matter experts, is a spacecraft development architecture that includes technology and standards developed to facilitate simplified design, assembly, and test of spacecraft systems using modular components to reduce spacecraft development cost and schedule. There is a need to assess the maturity of SPA to determine its benefits and return on investment. SPA, being a system and a combination of technology and standards, poses challenges for the maturity assessment. In this thesis, the author presents the methodologies to assess the maturity of SPA, using the existing Technology Readiness Level (TRL) process for technology and developing new process for the standards. The TRL process is applied to the technology components and the SPA system. The proposed process for assessing the maturity of the product development standards is similar to the TRL process, but tailored for applicability to standards. The methodology for assessing the maturity of SPA standards is based on the premises of what was done and under what conditions. Applying these methodologies to assess the maturity of SPA gives a complete picture of the status of SPA development, which is used to estimate the cost to reach full maturity with more accuracy.

Parobek, Lucas S. **"Research, Development and Testing of a Fault-Tolerant FPGA-Based Sequencer for CubeSat Launching Applications."** Master's thesis - Electrical Engineering, Naval Postgraduate School, 2013.
https://hdl.handle.net/10945/32882
Abstract: This thesis concerns various means of implementing fault tolerance in logic for use in a general payload processor design. The first specific application of this research is a sequencer developed for deploying CubeSats. The sequencer shall be capable of the timing and accurate deployment of multiple CubeSats from a host spacecraft and shall have the capability for quick reconfiguration prior to launch. This research considers a variety of hardware for suitability toward sequencer construction; field programmable gate arrays (FPGAs) are chosen as the primary device. The design further evolves to selection of the Actel ProASIC3 series of FPGAs. Initial logic test configurations are implemented on a development kit with analysis of results provided. Fault-tolerant techniques are compared with a set of experiments to determine optimum resource utilization and timing schemes. Triple modular redundancy (TMR) is selected as the technique for fault-tolerant logic implementation in the sequencer. Preliminary test boards are built via schematic design and printed circuit board layout. The manufacturing, integration and testing of the ProASIC3 Test Board is fully discussed. A follow-on flight prototype board is designed with more extensive hardware allowing for implementation of fault-tolerant techniques and future growth capability. Recommendations for future work are discussed.

Sears, Adam G. **"Design and Experimental Implementation of Optimal Spacecraft Atntenna Slews."** Master's thesis - Astronautical Engineering, Naval Postgraduate School, 2013.
https://hdl.handle.net/10945/39011
Abstract: This thesis investigates the development and implementation of optimal slew trajectories for positioning a spacecraft antenna. Conventional maneuvers are developed by considering each gimbal independently. Consequently, maneuver design is simple, but may be highly sub-optimal and cause significant torques to be imposed on the spacecraft body. This work explores the impact of implementing optimal slew paths that best utilize system dynamics with the objective of increasing available customer time on communications links and enabling new missions. Accomplishing this required the development of a detailed multibody system model that can be easily tailored to any spacecraft antenna configuration. Various software suites were used to perform thorough validation and verification of the Newton-Euler formulation developed herein. The antenna model was then utilized to solve an optimal control problem for a geostationary communications satellite. The developed maneuvers not only reduce the antenana slew time, but also reduce the impact of the antenna

motion on the spacecraft attitude. This reduces reliance on the spacecraft attitude control system to maintain pointing, and minimizes the impact of antenna motion on the operation of other payloads. Successful implementation of the designed maneuvers on a laboratory testbed validate the approach in a real hardware environment.

Slosman, Brian D. **"Design of Discrete Time Radio Receiver for the Demodulation of Power-Separated Co-Channel Satellite Communication Signals."** Master's thesis - Space Systems Operations & Electrical Engineering, Naval Postgraduate School, 2013. https://hdl.handle.net/10945/37719
Abstract: This thesis has two purposes: 1) to document the design of a discrete-time radio receiver for the coherent detection of a QPSK signal in the presence of additive white Gaussian noise; and 2) further research into the performance of representative receivers in the successive demodulation of power-separated, co-channel satellite communications signals. Several commercial companies are offering satellite modulators and demodulators that allow frequency reuse over satellite communications links. There are two methods to demodulate these co-channel signals. The first method requires a priori knowledge of one of the two signals linearly superimposed in the satellite downlink. With this knowledge, the known signal is cancelled using subtraction to reveal the unknown co-channel signal. A second method of recovering both signals is possible if adequate power separation of the two signals allows recovery of the strong signal. After recovery of the strong signal, the data can be re-modulated and then cancelled from the composite signal to reveal the weak signal. This method has the advantage of not requiring a priori information which widens the applications for layered modulation techniques to simplex, broadcast, and multi-cast network architectures.

Wilcox, Jeffrey. **"Content-Aware Adaptive Compression of Satellite Imagery Using Artificial Vision."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2013. https://hdl.handle.net/10945/37744
Abstract: This thesis aims to improve image throughput from satellite to Earth by using Artificial Vision to perform data compression before the downlink. Onboard Analysis for Selective Imagery Compression (OASIC) is a hybrid compression algorithm designed for oceanic imagery, incorporating both lossless and lossy compression methods to achieve a high compression ratio with minimal noise on vessels of interest. This is achieved by separating the vessels from the surrounding ocean and storing them with high fidelity, while compressing the remainder of the image with low fidelity. The performance of OASIC is examined on full resolution panchromatic satellite images and compared to both lossless and lossy JPEG2000 compressed images. In nearly all configurations tested, OASIC outperforms JPEG2000, achieving an average fifteen-fold improvement in compression ratios while maintaining a nearly lossless fidelity for the vessels within the OASIC compressed images. This content-sensitive compression algorithm can potentially enable the transmission of higher spatial resolution images, with more spectral bands, and at higher download speeds from space.

Yeau, Wenjie. **"Operational Analysis of Time-Optimal Maneuvering for Imaging Spacecraft."** Master's thesis - Space Systems Operations, Naval Postgraduate School, 2013. https://hdl.handle.net/10945/32922
Abstract: There is currently a gap in translating the performance enhancements made possible by new maneuver strategies into operational benefits derived for spacecraft missions. In the context of imaging satellites, slew time is one of the key factors that influences the economic performance of image collection operations. To analyze the operational benefits associated with adopting time-optimal maneuver strategies to reduce slew times, this thesis studies two different operational scenarios based on the Singapore-developed X-SAT imaging spacecraft. The analysis is facilitated through the use of AGIs Systems Tool Kit (STK) software. An Analytic Hierarchy Process (AHP)-based framework is proposed to evaluate, from a business analytic point of view, the impact of incorporating time-optimal maneuvers as part of X-SAT imaging operations. The business case analysis is focused on assessing key performance indicators such as image collection volume, collected image resolution and economic revenue.

The findings presented herein suggest that time-optimal maneuvers can enhance the value of imaging operations and provide additional revenue for satellite operators. Moreover, the proposed AHP hierarchy model was found to provide a convenient and methodical means for quantifying the operational advantages and economic Return on Investment (ROI) that can be obtained when incorporating new maneuver strategies into spacecraft operations.

Zaman, Farakh B. **"Building a Local Space Situational Awareness (SSA) Architecture Using Hosted Payloads."** Master's thesis - Systems Engineering, Naval Postgraduate School, 2013. https://hdl.handle.net/10945/37749

Abstract: From a military standpoint, space-based capabilities and the need to know what is happening in space, or Space Situational Awareness (SSA), have become invaluable. Current SSA capabilities are expensive and are limited in scope. Hosted payloads however, provide a unique method to provide SSA in a relatively inexpensive manner. This thesis explores the development of an architecture for SSA using hosted payloads. For this thesis, research was conducted on existing systems. NASA and Air Force programs were reviewed to gain an understanding of hosted payloads, and a set of generic high-level requirements were developed for a hosted payload. These requirements will meet the needs of a hosted SSA payload that can enable a larger SSA architecture using hosted payloads. Once the requirements were developed, modeling and simulation using Satellite Tool Kit (STK) was were employed to develop an optimal SSA system using hosted payloads. Finally, once the architecture was defined, an Operational View 1 (OV-1) was developed to provide a graphical representation of the architecture.