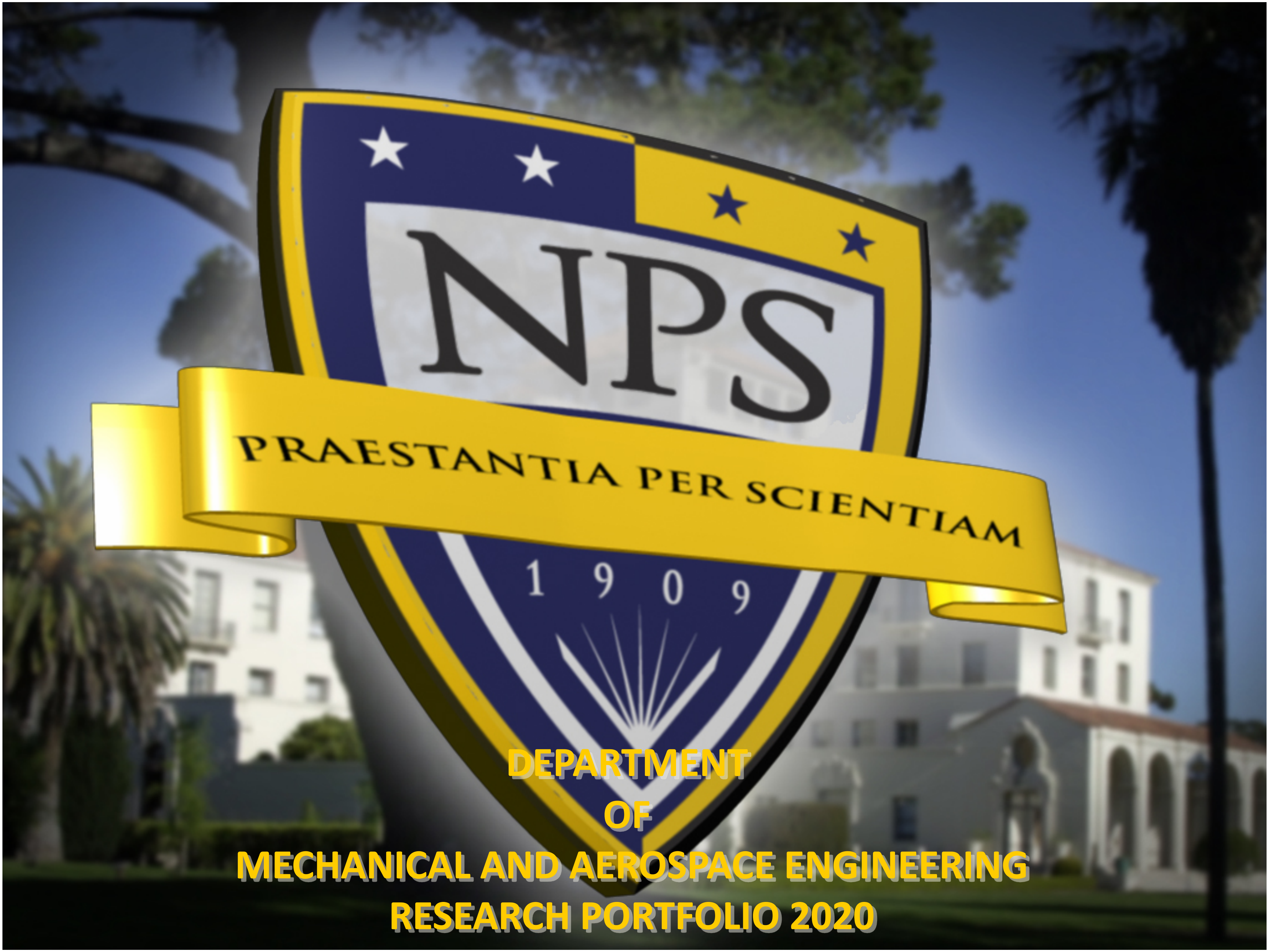


DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING RESEARCH PORTFOLIO 2020

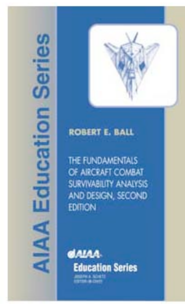
Center for Survivability & Lethality (CSL)
Aircraft & Ground Vehicle Survivability

Christopher Adams: caadams@nps.edu, 831-656-3400

Motivation

The CSL was established to covers a wide range of topics in both survivability and lethality including:

- Fixed and rotary wing aircraft (manned and unmanned)
- Surface ships and submarines
- Ground vehicles
- Personnel



What is a Survivable System?

A system w/ the capability to avoid (low susceptibility, measured by $\mathbf{P_H}$) or withstand (low vulnerability, measured by $\mathbf{P_{K|H}}$) a hostile environment.

Keys to Success

- The NPS faculty have great expertise in the analysis, design for increasing the survivability and lethality of military platforms, weapons, and systems.
- NPS students are warfighters, and consequently they bring a level of knowledge, experience, and judgment to their research that is not available anywhere else

Survivability Enhancement Concepts

Susceptibility Reduction (Avoid)

1. **Threat Warning & Situational Awareness**
2. **Noise jammers and deceivers**
3. **Signature reduction**
4. **Expendables**
5. **Threat suppression**
6. **Weapons & tactics, flight performance, & crew training & proficiency**

Vulnerability Reduction (Withstand)

1. **Component elimination/ replacement**
2. **Component location**
3. **Component redundancy**
4. **Passive damage suppression**
5. **Active damage suppression**
6. **Component shielding**

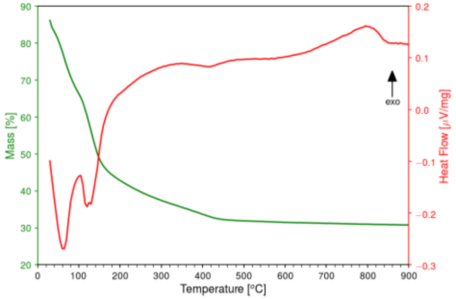
Materials Characterization Labs

Dr. Richa Agrawal, Dr. Chanman Park, POC: Prof. Troy Y. Ansell (troy.ansell@nps.edu, 831-656-3033)

Thermal Analysis (POC: Prof. Claudia Luhrs, ccluhrs@nps.edu, 831-656-2568)

STA

- Students and faculty use a simultaneous thermal analysis (STA) to characterize thermal behavior of materials from room temperature up to 1400 °C.

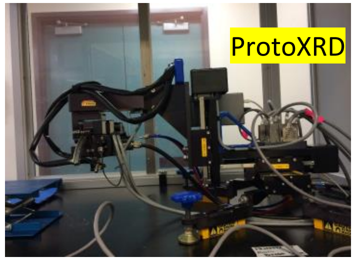


- Calorimetry performed in Ar and/or N_2 atmospheres.
- Facilities also present to conduct surface area and porosity of materials

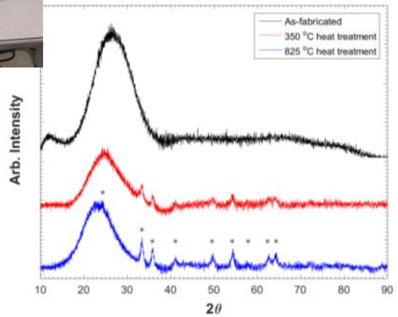
X-ray Diffraction

- Characterize microstructural phase, composition, and crystallinity of powder or bulk samples.
- Characterize crystal structure of metals, ceramics, polymers, and composite materials.
- ProtoXRD allows non-destructive measuring residual stress associated with failure by fatigue or stress corrosion cracking.

X-ray powder diffractometer

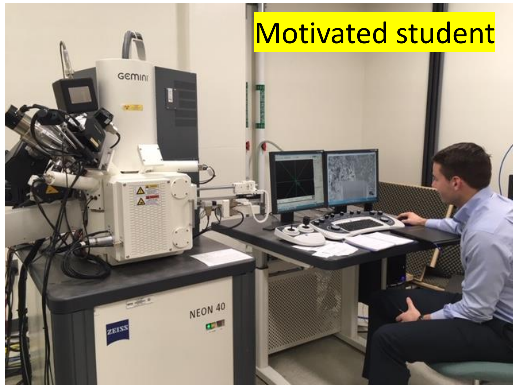


ProtoXRD



Scanning Electron Microscopy

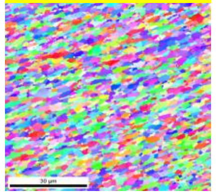
- Train students on basic physics and operation of scanning electron microscope (SEM) and energy dispersive spectroscope (EDS).
- Use SEM/EDS and attached equipment to support student classwork and thesis work and faculty research.
- Focused ion beam (FIB) allows micron-sized cuts of samples to be made. Used for TEM prep.
- Electron back-scatter detector (EBSD) used to image grain size, orientation, and sample texture (macro- and micro-sized).



Motivated student

FIB cut NPS logo

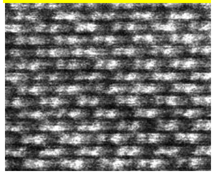
Orientation imaging



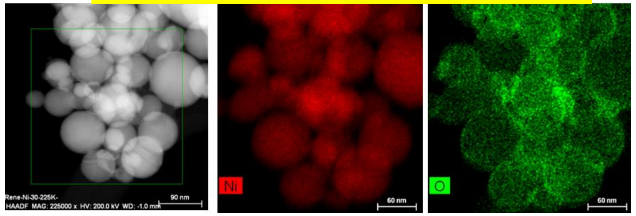
Transmission Electron Microscopy

- Transmission electron microscope used in support of faculty research. TEM work published in nine student theses and multiple research publications.
- Allows user to image and analyze samples in the sub-nanometer regime.
- High resolution quantitative chemical analysis with electron energy-loss spectroscopy (EELS).
- Electron diffraction for nano-scale crystallography.

Dumbbells in Si <110> resolved: 0.136 nm



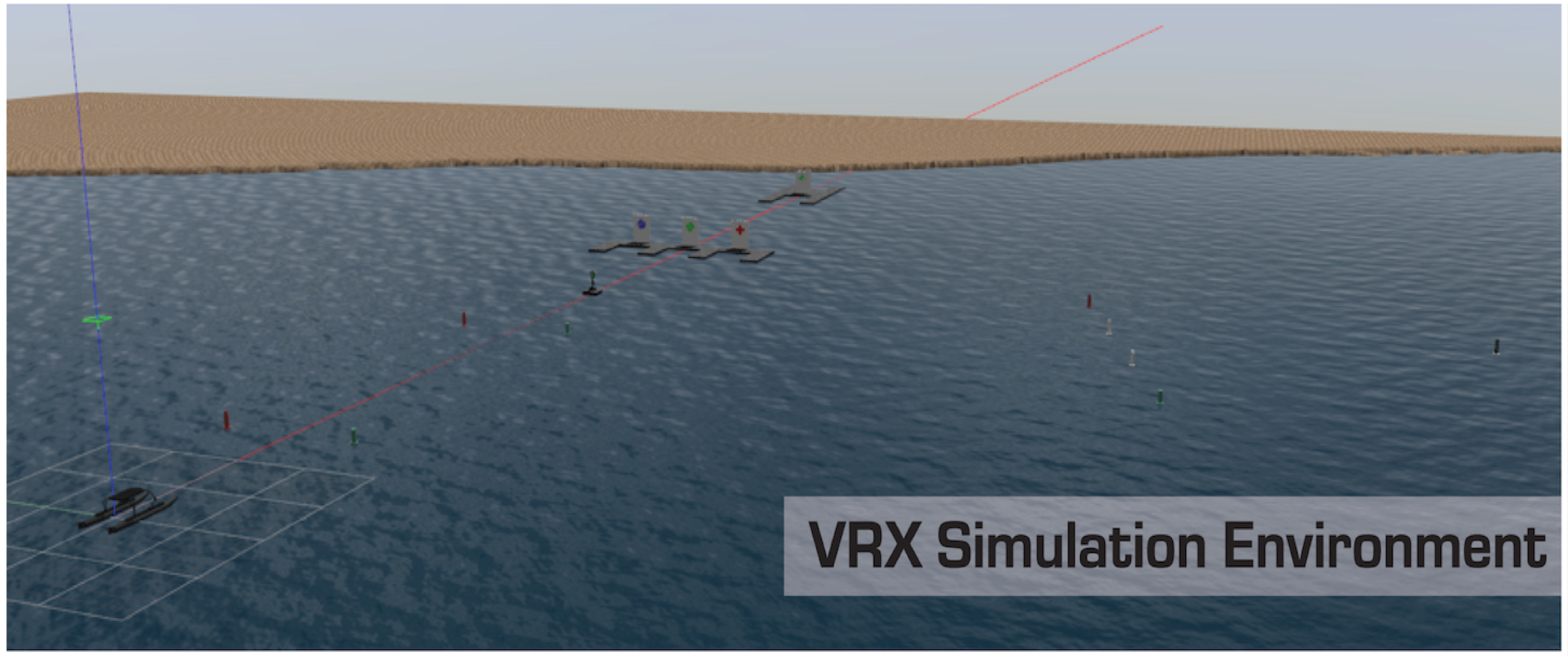
EDS maps showing oxide coating on Ni nano-spheres



- Capable of chemical analysis (EDS or EELS) of nanometer sized objects.

Virtual Environment to Support Ocean Robotics

Naval Postgraduate School



Gazebo simulation of Unmanned Surface Vesssel

Execution

- In collaboration with Open Robotics, NPS is creating an authentic, open-source virtual robotics environment to accelerate the development and evaluation of maritime robotics applications
- ONR, RobotNation, Open Robotics and NPS will create and host the 2019 Virtual RobotX (VRX) Challenge, as a complement to the ongoing ONR-sponsored Maritime RobotX Challenge.

Background & Objectives

- Simulation is a fundamental capability for rapidly developing robotic maritime applications.
- For much of the (non-maritime) robotics community the open source Gazebo robot simulator has emerged as the de facto standard environment for prototyping and testing robotic systems.
- Although many single purpose solutions are available, the maritime robotics community lacks such a ubiquitous, general-purpose simulation tool.
- This project will bring together existing tools and create the interstitial technologies to create a general purpose robotic simulation toolkit that will be immediately useful to maritime robotic projects in particular and multi-domain robotics projects in general

Relevance

- Development of maritime robotic technologies (USVs and UUVs) for Naval applications will benefit from improved connections with the larger robotics community.
- The open-source simulation tools will connect the maritime robotics community to the larger robotics community, allowing rapid adoption of existing and future new advancements.

Brian Bingham
Mechanical and Aerospace Engineering Dept.
bsbingha@nps.edu 831-656-2396

Consortium for Robotics Unmanned Systems Education and Research (CRUSER)

Naval Postgraduate School

CRUSER Innovation Thread

Activities

- Support Research and Concept Generation
  - 20+ seed research projects involving NPS thesis students
- Warfare Innovation Thread
  - Ideation -> prototyping -> experimentation
- Enhance Student Experience
  - Student travel: conferences, site visits and field work
  - Bringing research into the classroom
- Engage Community of Interest: ~3,000 Members
  - Military + Academia + Industry
  - Newsletter, monthly meetings and special events
- Enable Field Experimentation

Background & Objectives

- Established in 2001 by Under Secretary Robert Work, CRUSER is the SECNAV's program in unmanned systems at NPS.
- ONR is current resource sponsors, ~$4M/year.
- Mission
  - shape generations of naval officers through education, research, concept generation and experimentation in maritime applications of robotics, automation and unmanned systems
  - provide a DoD-wide community of interest to exchange research and experimentation results

Relevance

- Provides a source for unmanned systems employment concepts for operations and technical research.
- Provides an experimentation program to evaluate unmanned system employment concepts.
- Provides a venue for Navy-wide education in unmanned systems.
- Provides a DoD-wide forum for collaborative education, research, and experimentation in unmanned systems.
- Reaches across the Navy, Marine Corps, Department of Defense, academia, and industry.
- Collaborative environment for the advancement of unmanned systems education and research endeavors.

Brian Bingham, Director
Mechanical and Aerospace Engineering Dept.
bsbingha@nps.edu 831-656-2396

PASSIVE COOLING OF BUILDINGS; PCM COOLING

M.S. Chandrasekhara: mchandra@nps.edu
Sponsor: ONR/ESTEP

Stakeholders

- The US Navy, NPS and PI

Problem Statement

- Cooling of Navy facility spaces consumes significant energy and is a major expense
- Safe, passive cooling techniques are being evaluated to reduce energy demand and costs while still retaining occupants' comfort

Objective

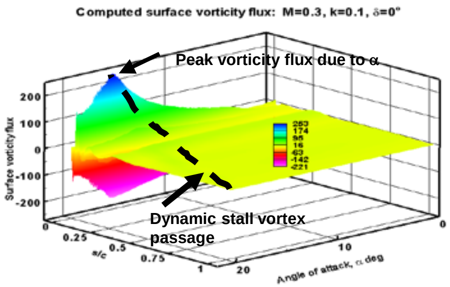
- Identify and size appropriate Phase Change Materials (PCM) for normal comfort level of room occupants
- Packaged energy panels suitable for use as drop-ceilings, behind dry walls, etc. in NPS/MAE lab environment
- Take appropriate measurements to establish the viability of each approach and PCM

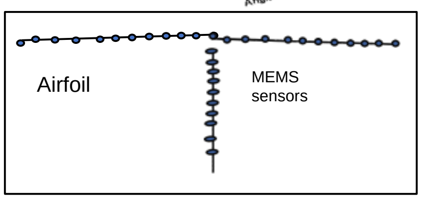
Panels actively absorb heat when room temp exceeds the set point

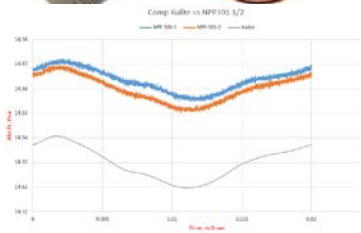
Panels release stored heat when room temp falls below the set point

CAN LEADING EDGE ADVERSE PRESSURE GRADIENT BE QUANTIFIED TO SERVE AS PRECURSOR TO COMPRESSIBLE DYNAMIC STALL ONSET?

M.S. Chandrasekhara: mchandra@nps.edu
Sponsor: US Army AvMC/AFC; Moffett Field, CA







Sensor response to 250Hz input pressure wave

Innovation: Dynamic stall vorticity production is directly related to the unsteady flow dp/dx, whose control is critical to flow vorticity management. As it is the precursor to DS onset, systematic measurement of evolving dp/dx is vital, but has not been possible so far. Using commercial MEMS sensors, which due to their micro size, satisfy gradient sensing spacing requirements, it now seems possible. Two families of MEMS from Amphenol sensors were evaluated, with both delivering adequate range and dynamic response. The technology is now being adapted for use in airfoil studies with the NPA-301 sensor as preferred family due to its analog output and ease of integration with in-house DAQ system.

Problems/Questions: Dynamic stall vorticity production is intimately dependent on the naturally developing flow adverse pressure gradient, whose direct measurement has hitherto been impossible. DS control requires flow vorticity management, which requires the evolving pressure gradient information. Can the rapidly evolving leading edge adverse pressure gradient be reliably quantified? Can it be correlated with dynamic stall onset for different conditions? Answers to these key questions will enable successful development of a control method.

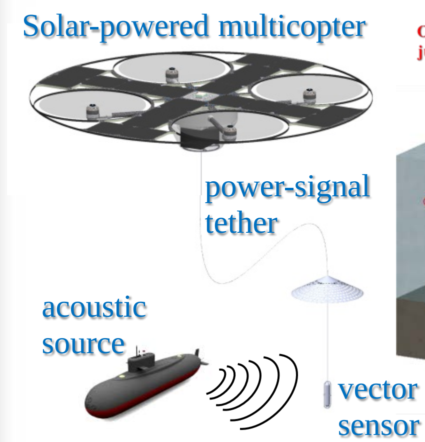
Theoretical Basis for Research To avoid, control and sustain the benefits of the phenomenon, its vorticity production and convection balance should be maintained. Also, open loop control efforts with leading edge adaptation to flow conditions have successfully demonstrated complete dynamic stall control. Implementation in flight systems requires a more educated and closed loop control methodology, which the information being sought in these studies can help build.

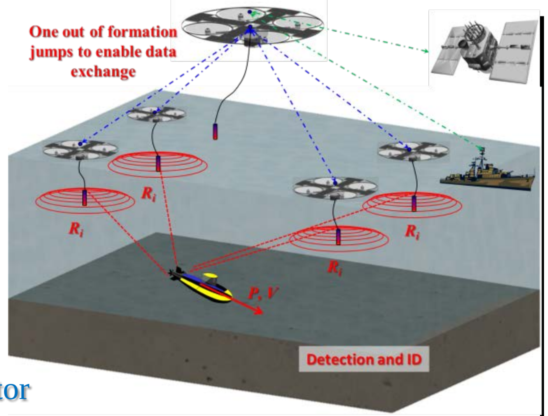
Relevance to DoD Mission: Avoiding/eliminating or controlling/mitigating dynamic stall means improved rotor that leads to a superior helicopter. Research results could even be applicable in other DoD efforts such as unmanned vehicles.

NAVAL POSTGRADUATE SCHOOL

Solar Powered, Long Endurance, Hybrid Mobil Buoy for Persistent Surface and Underwater Reconnaissance

CAVR
NPS CENTER FOR AUTONOMOUS VEHICLE RESEARCH





Concept of swarming mission

Objectives - Develop a water-tight, buoyant, self-righting multi-copter with a solar recharge capability, that can float on the ocean surface with a submerged sensor suite for passive or active sensing. The buoy would recharge batteries during sunlight hours allowing for continuous sensor use and occasional flights above the ocean surface for advantaged communications and/or relocation.

Concept - Combine benefits of low cost and agile autonomous multi-rotor capable of *lifting* a significant payload and carrying sufficient *computational* and *communication* capabilities with the *detection* capabilities of light weight passive sonar and high performance *solar panels* capable of charging the flying buoy in a matter of hours.

Key challenges: *Long distance communication* in rough seas requires significant elevation and stabilization of communication antennas. The ability to relocate acoustic sonar sensors rapidly to a required location is a desired tactical advantage not easily available at present.

Optimal conservation and expenditure of constraint power resources for propulsion and communication.

Technology thrusts: Solar and seawater-driven batteries, sensors, efficient comm. links, low-power adaptive embedded computing, classification of acoustic signals, and RT signal processing.

Applications:

- Undersurface warfare
- Marine habitat tracking
- ICBM launch detection
- Meteorology and Oceanography
- Pollution tracking
- Underwater-space comm. relay

MAE M.Sc. Candidate: 1-2 students per year

Key Participants (CAVR faculty, MAE):
K.D. Jones, V.N. Dobrokhodov , {jones, vldobr@nps.edu}

Key Deliverables and Milestones

Phase I - Proof of concept &platform design:

- Flyable platform suitable for water landing and takeoff under first manual and then autonomous control with positive buoyancy and self-righting stability in the water.
- Solar recharge system integration with a flight/recharge/flight demonstration.
- Autonomous launch, navigation and landing using an integrated autopilot and GPS navigation.
- Integration of passive acoustic sensors, data-logging and signal processing with pop-up and transmit flight mode.

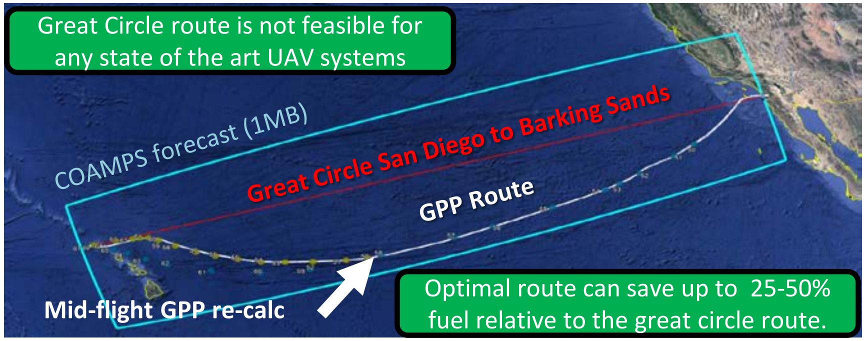
Phase II – Integration of the platform into application scenarios:

- Energy management algorithms for extended mission endurance
- Navigation and signal processing for objects detection and tracking
- Decentralized coordination for improved operation effectiveness

2 U.S. patents awarded: U.S. 9,321,529 ; U.S. 9,457,900 B1

Multi-Day Endurance of a Group 2 UAS Utilizing Pacific Energy Sources

Motivation – enhance current mission effectiveness via advanced energy behavior (DOD Operational Energy)



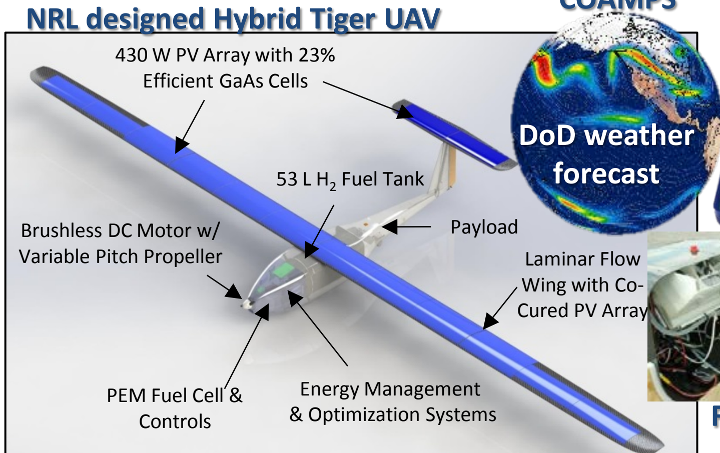
Objective – advance operational energy strategy:

- Increase future UAV capability via adaptable use of various sources of energy
- Enhance current mission effectiveness via predictive energy forecast and optimal routing
- Identify and reduce risk of energy shortage via robust adaptive mission replanning and intelligent control

Concept – demostrate synergistic range and endurance benefits by integrating fuel cell propulsion, soaring, solar harvesting, and optimal path planning.

Approach – integrate the latest advances in energy storage, harvesting, and recovery technologies in the novel onboard software capable of rapid *energy optimal global path planning (GPP).*

NRL designed Hybrid Tiger UAV



COAMPS

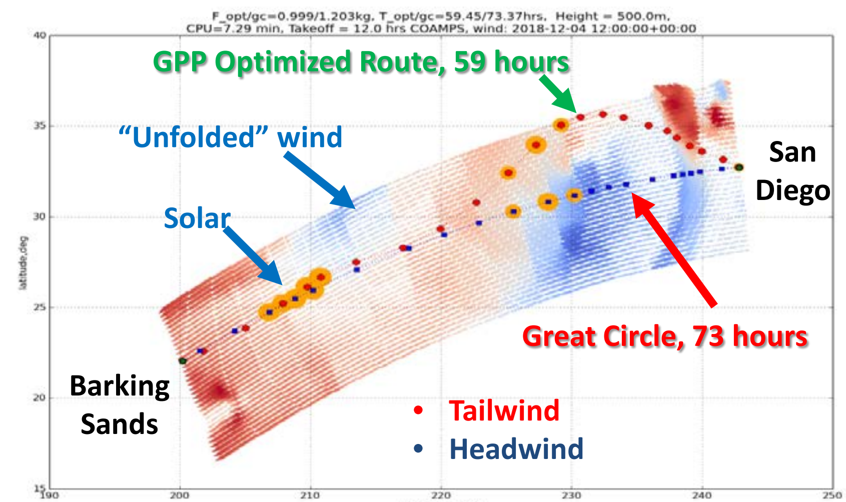
DoD weather forecast

Advanced CPU

Fuel Cell & H2 Fuel Storage

Solution – minimum energy/fuel solution obtained by utilizing classical Pontryagin optimal control approach.

Key Deliverable - previously not feasible routes (CA-HI) can be optimally flown and rapidly recomputed onboard.



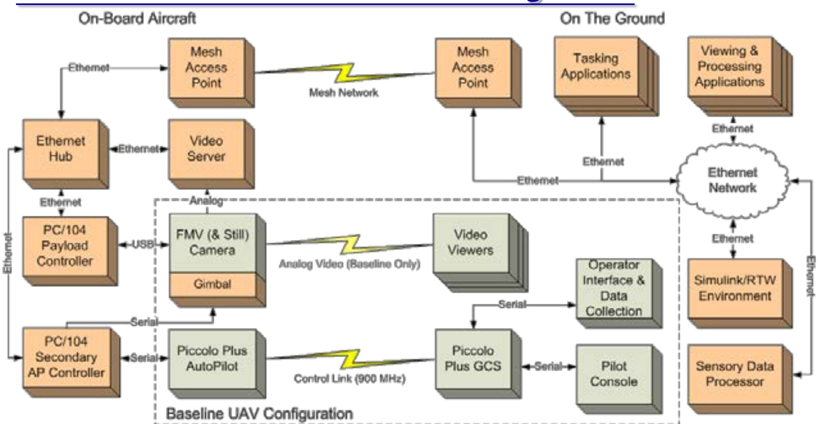
Patent: U.S. PTO 16/155,968, U.S. PCT PCT/US18/55144

Key Participants (CAVR faculty, MAE):

Vlad Dobrokhodov, Kevin Jones, {vldobr, jones}@nps.edu

Cooperative Flight Control Prototyping System

Scalable IP-based architecture of single UAV



Key functionality of the system:

- Rigorous theoretical approaches to multiple UAVs path planning, cooperative control design and verification.
- Model-based approach to control design and integration that is driven by mission objectives.
- Focus on cooperative execution by heterogeneous UAVs
- Unified and modular IP-based Hw/Sw architecture.
- Adoption of advanced mathematical tools and methods for algorithms design and implementation.
- Ability to conduct rigorous flight verification and validation of multiple UAV missions in restricted airspace.
- Understanding of objectives in various applications.
- Theory and technical solutions feasible for integration in class-room environment.
- Rapid code generation and seamless integration onboard with feasibility constraints in mind.

POC: Vlad Dobrokhodov, vldobr@nps.edu; Kevin Jones Jones@nps.edu; Isaac Kaminer, kaminer@nps.edu

Objective: Provide verifiable means of design and in-flight validation of novel cooperative control strategies for multiple heterogeneous UAVs.

Capabilities:

Theory	Software	Instrumentation
• Coordinated path following robust to degraded comm. • L1 theory of fast and robust adaptation • Vision-Based Robust Target Tracking • Multiple agents path planning	• GNC development in MatLab/Simulink. • Autocoding and V&V tools. Hard/soft RT execution. • ROS/SPREAD messaging & comm. • Optimal use of CPUs with Linux integration	• Unified avionics setup. • Open architecture. • Self config. MANET. • Circuitry and electronics design for novel sensors and integration. • Rapid hardware prot. and 3D printing.

Fleet of heterogeneous UAVs and payloads

Piccolo AP

HRI

IP cam

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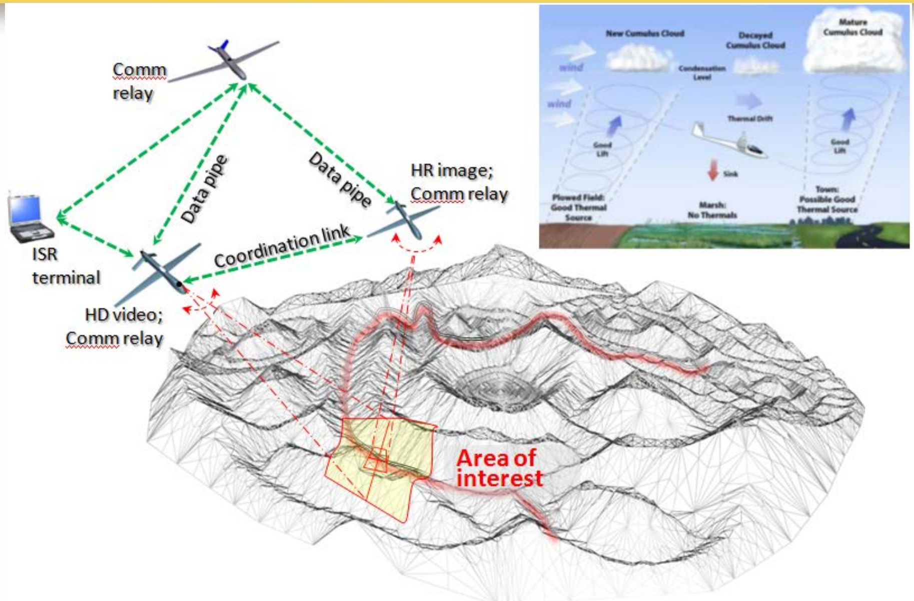
Improving Operational Effectiveness of Tactical Long Endurance Unmanned Air System (TaLEUAS) by Utilizing Solar Power

CAVR
NPS CENTER FOR AUTONOMOUS VEHICLE RESEARCH



Objectives:
Develop a system of multiple cooperating autonomous gliders that harvest thermal and solar energy to achieve extended endurance that will be used to provide long duration network and communication coverage in a typical ISR mission.

Key idea is in developing and implementing onboard of tactical autonomous gliders a set of distributed coordinated energy sensing and accumulation algorithms that will significantly extend their flight endurance and thus reduce the need for external energy supplies while improving the efficiency of ISR and communication support.

Envisioned Scenario: A team of autonomous gliders is launched by the marines from a friendly area to provide ISR sensing along with network and communication coverage. The gliders use a combination of solar and thermal energy harvesting algorithms and instrumentation and remain airborne for extended time; for 3-5 days or as needed. When airborne, the gliders operate either in a distributed fashion over an extended area of operation, or they provide a more focused support for high-value local targets. The latter may include cooperative distributed sensing to achieve precision strike support, tracking of ground targets, convoy following, etc.

Key Deliverables and Milestones:
- Algorithms for integrated energy harvesting that determine the minimum number of gliders needed to cover a given area of operation
- A single integrated (solar+thermals) glider that can autonomously operate in a typical ISR scenario. This phase is underway currently supported by the ARL office funding.
- Multiple cooperative gliders in multiple day ISR mission -
- Publications at AIAA and IEEE conferences on autonomous systems

Key Participants (CAVR faculty, MAE):
Prof. K.D. Jones, V.N. Dobrokhodov,
C. Walton, I.I. Kaminer

Non-Standard Navigational Methods for Unmanned Aerial Vehicles (FY20)

NAVAL POSTGRADUATE SCHOOL

NPS CENTER FOR AUTONOMOUS VEHICLE RESEARCH

Motivation

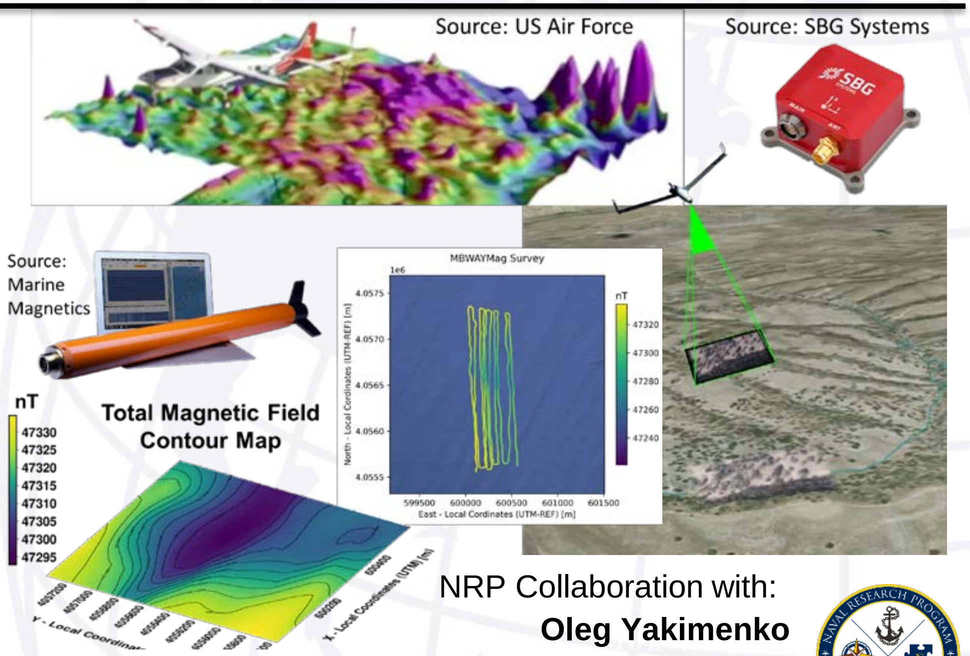
- Unmanned Aerial Vehicles (UAVs) are overly reliant on the Global Positioning System (GPS).
- In absence of GPS, alternative navigation fixes are needed to reduce inertial localization errors.
- Map-based navigation methods can enable continuous UAV operations without GPS.
- Geomagnetic maps can be effective when flying in areas without recognizable visual features.

Objectives

- Investigate proven inertial and geomagnetic navigation methods for autonomous underwater vehicles (AUVs).
- Develop trajectory generation and path following algorithms so UAVs can autonomously visit map features to obtain an external navigation fix.
- Test new algorithms using sensor (inertial & camera) and computer payloads for the NPS ScanEagle UAV.
- Conduct field experiments with a survey quality magnetometer to generate geomagnetic maps.

Results

- New Naval Information Warfare Center-Pacific payloads for ScanEagle UAV
  - –SBG Ellipse-N inertial measurement unit
  - –NVIDIA Jetson TX2 computer for NPS CAVR backseat driver interface
- Verified software interfaces for calibrating the IMU magnetic sensor, simulating GPS failures, and receiving camera data in flight
- Tested multi-threaded Python implementation of optimal trajectory generation algorithms



Sean Kragelund
spkragel@nps.edu
831-656-1159

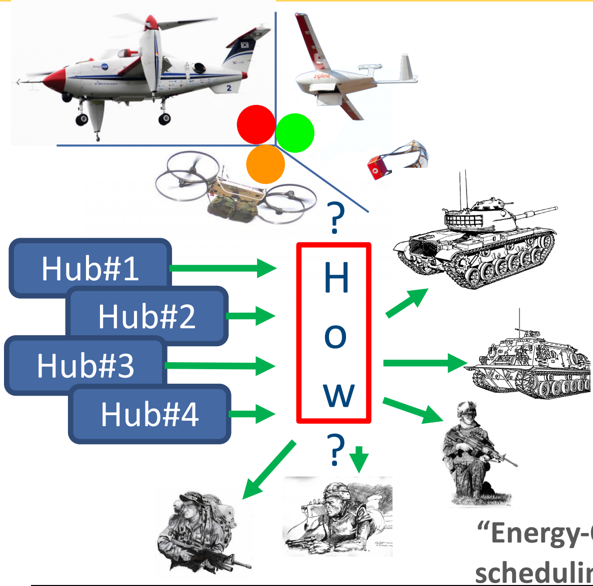
Aurelio Monarrez
amonarre@nps.edu
831-656-3775

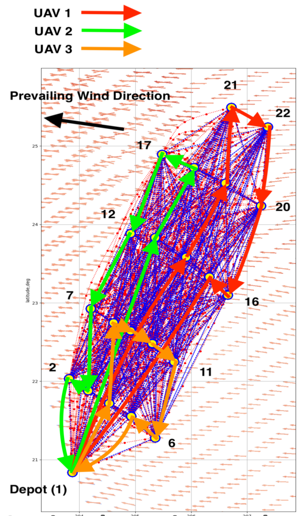
Isaac Kaminer
kaminer@nps.edu
831-656-3459

NRP Collaboration with:
Oleg Yakimenko
oayakime@nps.edu
831-656-2826

Energy-Aware Aerial Logistics in Support of USMC EABO Operation

CRUSER
Consortium for Robotics and Unmanned Systems Education and Research





"Energy-Optimal routing and scheduling achieved in FY20"

Problem Statement

- USMC EABO concept needs intelligent logistics that can move supplies from many small depots to widely dispersed forces with minimum energy footprint.
- Challenges of autonomy: limited range & endurance & payload capacity, dependency on weather.
- Challenges of logistics: complex network on the move, many logistics hubs, limited capacity delivery vehicles.

Solution – develop energy-aware routing algorithms to support EABO logistics with autonomous aircraft flying the energy optimal paths.

Impact

- The combined optimization significantly (10-25%) reduces energy consumption by UAVs across the logistics graph.
- Organizing deliveries by priority ensures that "urgent" requests are supported before "routine" requests.
- Autonomy is used to its full extent while combining the capabilities of aircraft and intelligent logistics SW.
- In the real world, energy savings mean longer range, increased carrying capacity, and fuel savings.

Transition

- Multi-Depot Multi-Salesman Vehicle Routing Problem(VRP) to identify optimal placement of resources and UAVs.
- VRP with time windows in order to better support time-specific demands from Marines on the ground.
- Flight energy characterization of hybrid multicopters and tilt-rotor aircraft.
- Integration of VRP solver into the ARL/SURVICE common control module of UAVs.

NPS

Seed Research Program 2021

PI: Vlad Dobrokhodov, MAE Department
Co-PI: Kevin Jones, MAE Department
Co-PI: Emily Craparo, OR Department

Compressed Air Energy Storage at Building Scale.

Motivation

A Robust and Reliable Energy System.
Targeted microgrids for critical circuits or systems.

ONR Led

ESTEP: Energy Systems Technology Evaluation Program.
A program for evaluating new and nascent technologies or systems.

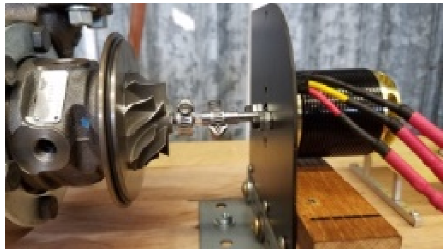
ESTEP
MISSION • PEOPLE • TECHNOLOGY

Enabling Technologies

Microgrids.
Compressed air energy storage (CAES).
Supercapacitors.
Rare earth motor-generators.

Faculty

Anthony Gannon ajgannon@nps.edu

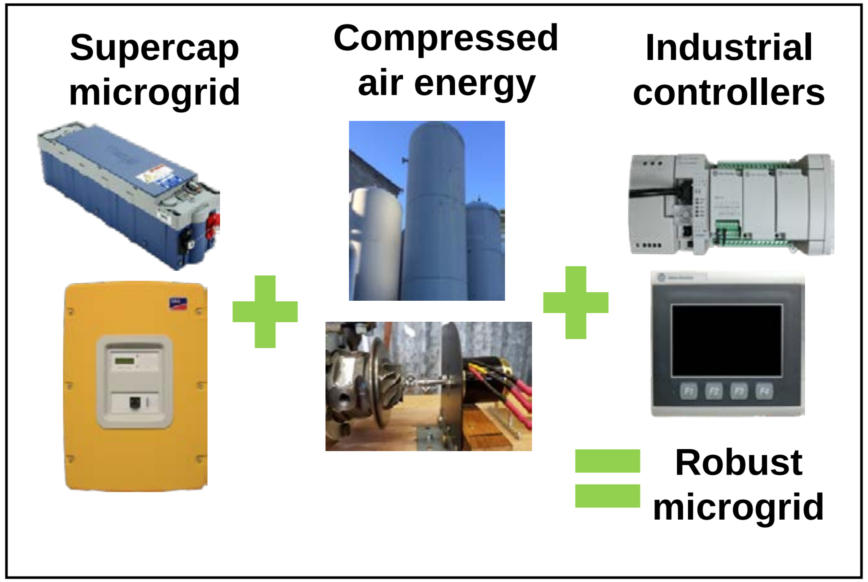


Challenges

Integration of technologies.

Robust automation of system.

Lack of standardization.

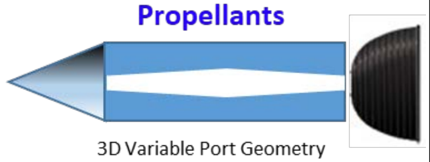


Additive Manufacturing of Solid Propellants

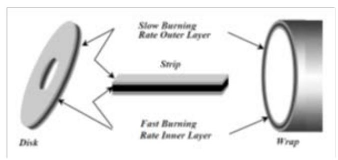
Prof. I. Emre Gunduz, emre.gunduz@nps.edu, 831 656-6288

Motivation

- 3D printing of propellants can improve performance and safety
- Reduce environmental impact of fabrication



3D Variable Port Geometry for Thrust Control

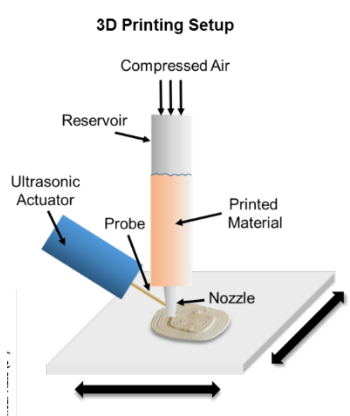


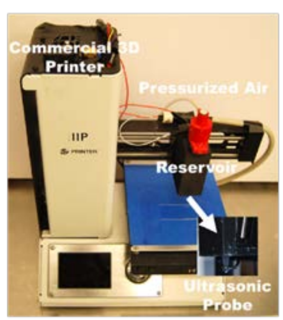
Mission

- Use a novel direct-write 3D printing platform that can print extremely viscous propellant precursors at high speed and resolution
- Improve range and energy density
- Low-vulnerability formulations
- Reduce use of solvents and number of processing steps

Technical Information

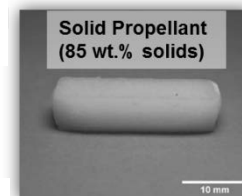
- Vibration-assisted printing can process materials with clay-like consistency
- High solids loadings with minimal porosity for highest energy density

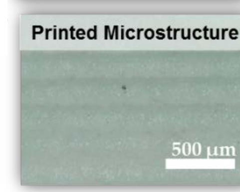


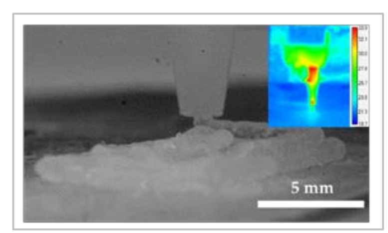


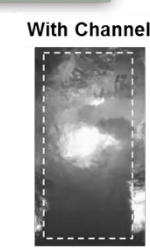
Summary

- Solid composite propellants at directly fieldable compositions can be 3D printed safely at mild print settings
- Investigating gun propellant analogue formulations
- Apply to other energetics









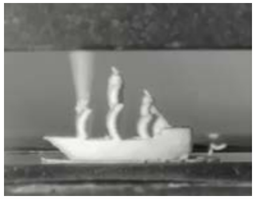
SERDP
DOD · EPA · DOE

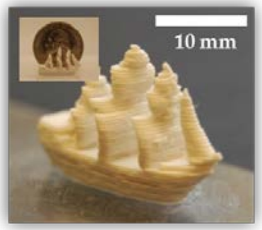
Net-shape Additive Manufacturing of High Temperature Ceramics

Prof. I. Emre Gunduz, emre.gunduz@nps.edu, 831 656-6288

Motivation

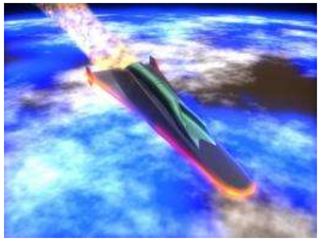
- 3D printing of ceramics for heat shielding can improve their performance while reducing weight
- Control thermal properties through geometry and composition





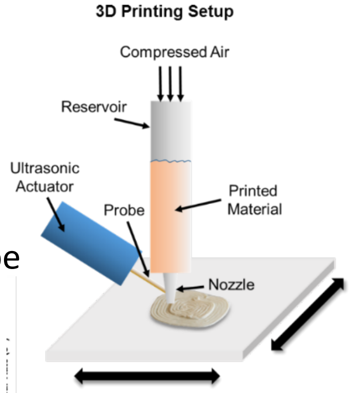
Mission

- Use a novel direct-write 3D printing platform for printing ceramic particle/ceramic forming polymer composites
- 3D print rocket nozzles and heat shields for re-entry vehicles with fine features
- Reduce weight and improve thermal protection



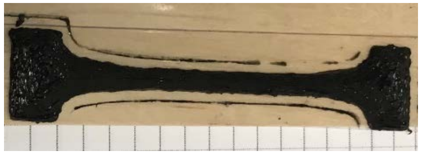
Technical Information

- Vibration-assisted printing of SiC powders mixed with SiC-forming polymers, following prior work on Graphite/Si-C-O system
- Thermal post-cure to net shape part without re-infiltration
- 3D printing channels and fast diffusion paths into structure for efficient heat removal
- High structural integrity

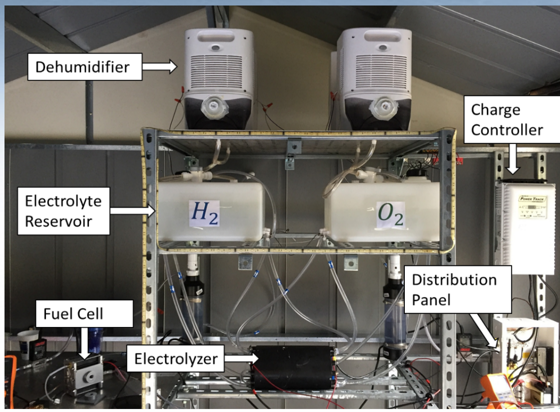


Summary

- Graphite short fiber powder/SiC-Oxide forming polymers were 3D printed to net shape with little porosity
- Extending the same methodology to SiC powder/SiC-forming polymers and other systems



ESTEP - Self Contained Hydrogen to Electrical System



Problem Statement

- This system demonstrates reliable and resilient renewable energy usage with storage as a cost alternative or emergency back up to traditional battery or gasoline operated systems. It can also be presented as a method to reduce DoD carbon footprint. This compact solar powered system can be used to generate power and H2 on demand for various DoD uses such as forward operating bases.

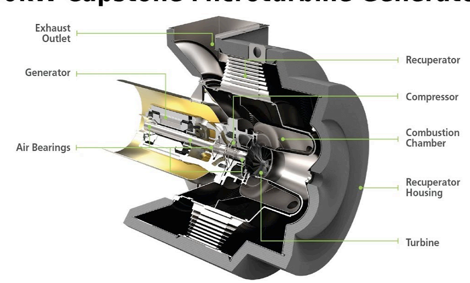
Objectives

- An ambient pressure solar powered H2 generator has been demonstrated to support fuel cell operation.
- The system is scalable for H2 electrochemical compression and storage.
- This compact system allows portable on demand capability.
- Electrochemical hydrogen compression is a significant new technology demonstration on this project.
- Energy can then be stored as H2 or used to supply loads such as a backup generator.
- Operation of a microjet (JetCat) and turbogenerator (Capstone C30) on H2

Funding

– FY 19 $100k
– FY 20 $100k
– FY 21 $100k

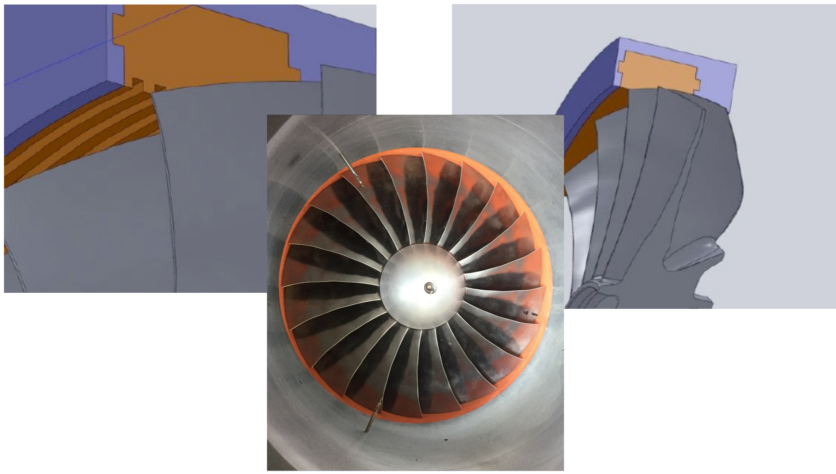
30kW Capstone Microturbine Generator



POC's

– PI; Garth V Hobson, gvhobson@nps.edu, (831) 656-2888
– Co-PI; Anthony Gannon, ajganon@nps.edu, (831) 656-2880
– Co-PI; Walter Smith, walter.smith@nps.edu, (831) 656-2593

Advanced Casing Treatment for Transonic Compressor for Improved Operability without Adverse Effect on Performance



Objective/Description

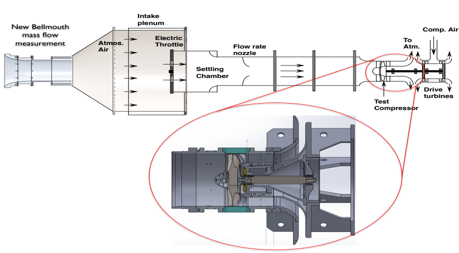
– Optimize compressor aero performance while also maintaining sufficient levels of stability margin throughout the operating range. To allow designers to continue to produce aggressive stage loading and improved stage stability characteristics without sacrificing performance.

Key Technologies

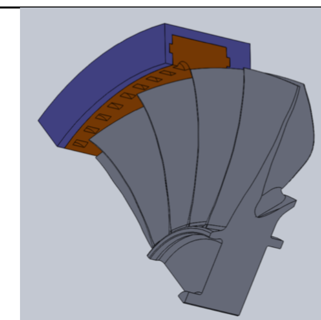
– Provide compressor designers the design rules they need to optimize a Axial Grooved Casing Treatment for either stability margin, efficiency, or an optimum trade of both.

Schedule/Milestones

- Peer Review: 3/6/20
- POP: FY19 – FY 21
- Task 1: Baseline and circumferential grooves over a rotor configuration
- Task 2: Baseline and circumferential grooves over a stage configuration
- Task 3: Targeted grooves over a stage configuration.



Funding



– N00014-17-WX01227
– FY 19 $250k
– FY 20 $300k
– FY 21 $350k

POC's

– PI; Garth V Hobson, gvhobson@nps.edu, (831) 656-2888
– Co-PI; Anthony Gannon, ajganon@nps.edu, (831) 656-2880
– Co-PI; Walter Smith, walter.smith@nps.edu, (831) 656-2593

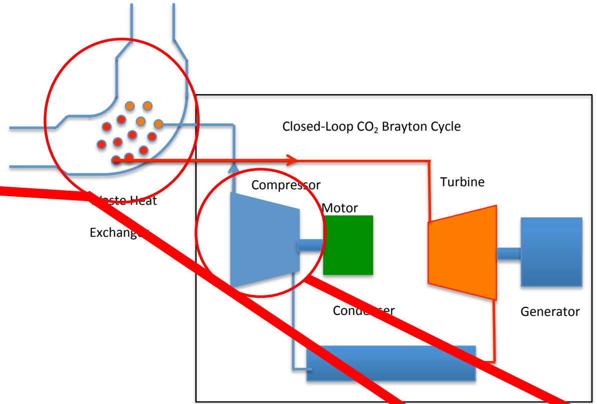
- NAVAIR; Josh Gilbert, Joshua.m.gilbert@navy.mil

Waste Heat Recovery From Gas Turbine Exhaust

Prof. Garth Hobson, Doug Seivwright
Students LT Aaron VanDenBerg, LT Coria Buck, LTJG Michael Kaim

Marine Propulsion Laboratory

Waste Heat Recovery System



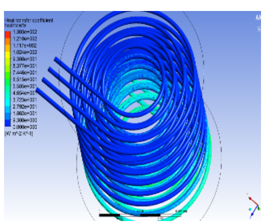
Integrated Electric Gas Turbine Concept

Background/Objective

- Gas Turbine thermal loss ~50-55%
- Develop waste heat recovery system to harness this resource
- Increase efficiency in recovery of heat utilizing organic working fluids (CO_2)
- CO_2 Non-Corrosive

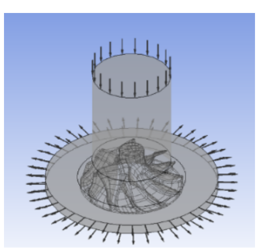
Approach, Analysis and Design

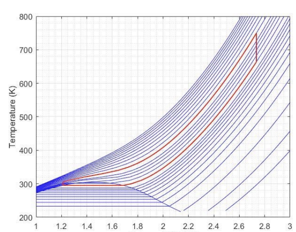
- Analysis of Organic working fluids to harness low quality waste heat.
- Develop Organic closed loop system
- Evaluation of efficiency of the combined system (Gas Turbine and Waste Heat Recovery)



CFD Modeling to minimize backflow pressure on engine while maximizing heat transfer of heat exchanger

ANSYS modeling of CO_2 Compressor





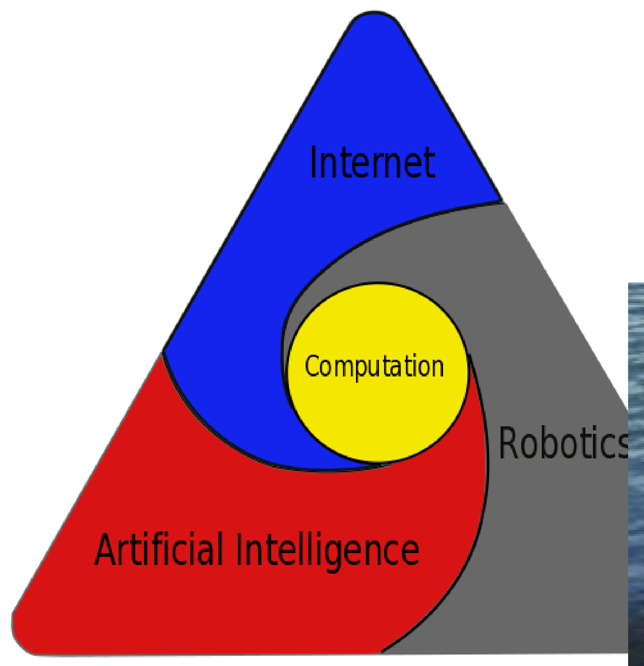
Cycle Analysis using CO2 as Medium

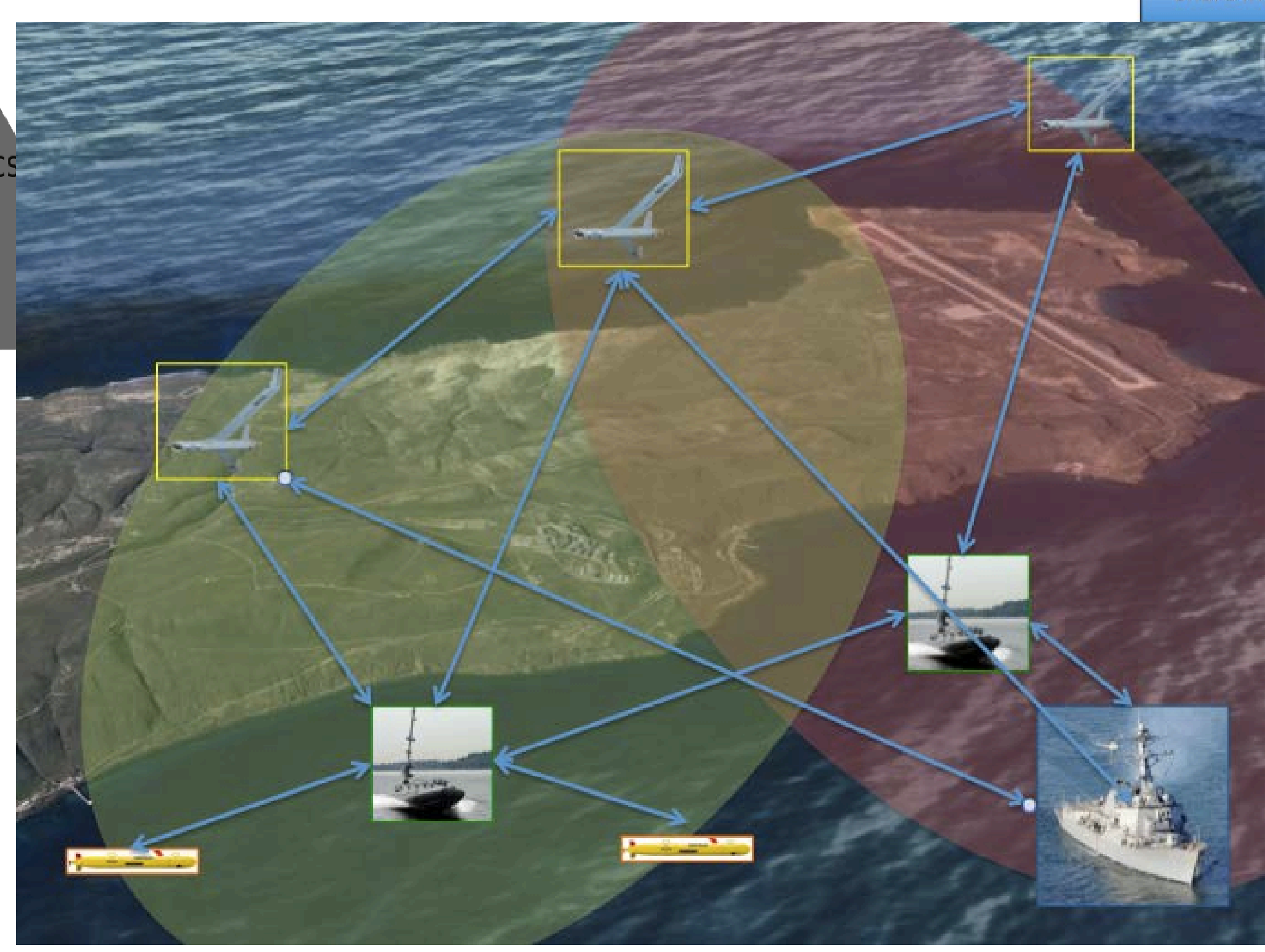
Summary

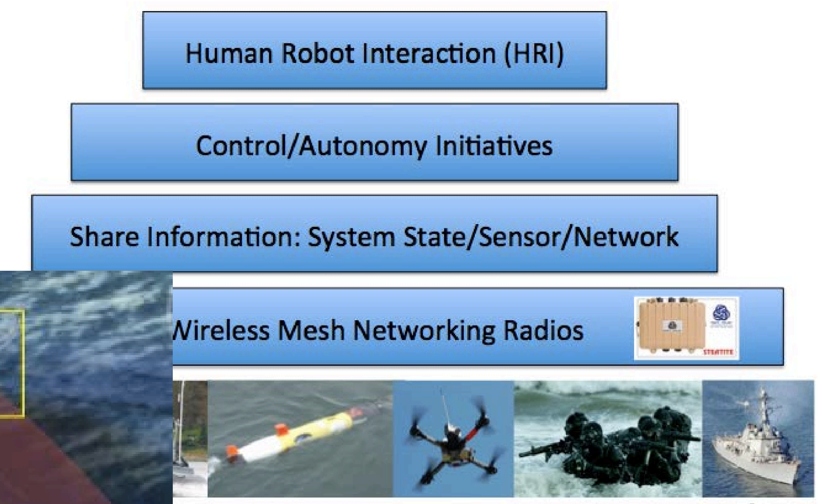
- Brayton loop construction completed
- Heat Exchanger and CO2 compressor designed and manufactured in house.

Distributed Adaptive Submodularity for UxV Network Control Systems (NCS)

CRUSER
Consortium for Robotics and Unmanned Systems Education and Research







How

- Modify Adaptive Submodularity approach from a centralized approach to a distributed approach.
- Include convergence proofs for the decentralized approach that utilize Spectral Graph theory for guarantees of system robustness.
- Refinement of Center of Autonomous Vehicle Research (CAVR) Robotic Operating System (ROS) based software, CPUs and mesh radio based hardware module for "add-on" to UxV systems for quick NCS assimilation.
- Develop Virtual Reality environment together with HIL simulation to enable concept experimentation with large numbers of UxVs.
- Combine together VR, HIL and physical systems into a single experiment. Permits bringing disparate deployments of AUV/USV/UGV/UAVs into a single environment

Deliverables

- A distributed, near optimal, high level controller for UxV Network Control System (NCS) based on the Machine Learning approach of Adaptive Submodularity.
- A modular plugin that includes software, hardware and communications for rapid assimilation of UxV into a NCS.
- An experimentation framework for UxV NCS algorithm and scenario testing. It combines together Virtual Reality, Hardware in the Loop (HIL) simulation, network simulation and (field deployed) physical UxV systems.
- UXV NCS experimentation utilizing UxVs together with Persistent Mesh Relay wireless communications as a single system.

Operational Impact

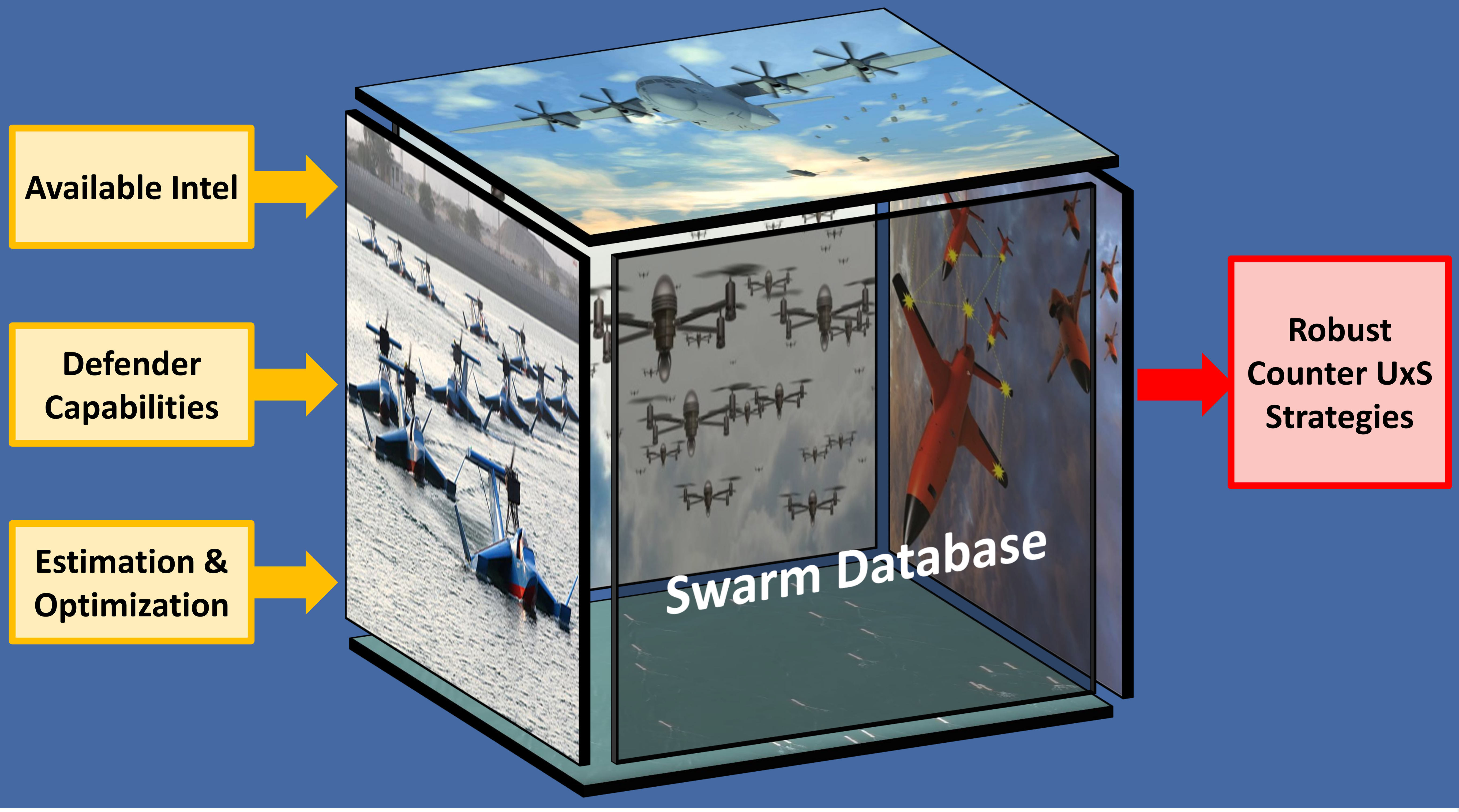
- Moving from a centralized approach to a distributed optimization is a challenging research problem with a high potential operational benefit.
- A hybrid UxV NCS that can work as a distributed or centralized system. Pros and cons
  - Centralized has a single point of command and control with a rapid response
  - Discentralized doesn't have a single point of failure and is more robust.
- Modular UxV NCS plugin permits taking off the shelf systems and rapidly incorporating them into the NCS.
- Novel experimentation framework permits exercising large numbers of UxVs without the cost.

NPS
PRAESTANTIA PER SCIENTIAM

Dr. Douglas Horner MAE
dphorner@nps.edu
831-747-4424

Robust Counter UxS Strategies Against Multi-Domain Super Swarms

CRUSER
Consortium for Robotics and Unmanned Systems Education and Research



- Optimize defensive strategies for robustness against variable swarm tactics
  – Swarm cooperation mechanisms are a **black box** to defenders
  – Develop robustness guarantees against this uncertainty
- Analyze thousands of counter-swarm scenarios to quantitatively assess
  – Defender capabilities matrix, asset allocation, attacker type/priority
- Develop universal counter UxS strategies that
  – Don't require *a priori knowledge* of attacker swarming algorithms
  – Ensure engagement outcomes are *robust vs. unknown swarm tactics*

Why

- Large-scale adversarial swarms are an imminent threat
- Future adversarial swarms will employ multiple, switching tactics
- Defensive strategies must be robust to uncertainty of sophisticated swarms

Objectives

- Robustness guarantees against highly uncertain threat
- Quantitative metrics for mission success/failure (risk)
- Estimation/Optimization/Analysis tools
- "**Super Swarm**" scalability, from O(10) to O(10^6) agents!

- Robustness training database
  – Scalable counter-swarm engagement database, multiple defensive & offensive tactics, available to NPS, ONR, and DoD researchers
- New metrics for quantifying mission risk/success against adversarial swarms
  – e.g., # of perimeter penetrators, # of lost defenders, etc.
- Asset Allocation Estimates for counter UxS/swarm defense
- Fundamental research findings shared through:
  – Student theses, class projects, CRUSER reports/ presentations
  – conference and journal publications
  – **xSwarm, Counter-Swarm 2020 Workshop**

FY20 Call for Proposals

Prof. Isaac Kaminer
kaminer@nps.edu, 831-656-3459
MAE Department

Research Asst. Prof. Claire Walton, MAE
Research Asst. Prof. Sean Kragelund, MAE
Prof. Wei Kang, Applied Math

Multi-Domain Super Swarm: Robust Tactics for Engaging an Attacking Large-Scale Swarm

Approach

- Extend existing computational optimal control framework to super swarm challenges by integrating the following components:
  - Air, surface and sea motion models.
  - Multi-domain communication modalities (RF and ACOMMS).
  - Multi-domain damage models.
- Simulation-based and experimental evaluation of the following scenarios:
  - Countering red team through exploitation of super swarm fragility
  - Composition of blue team super swarm for offensive engagement
- Leverage existing and future NPS facilities for experimental assessment of multi-domain autonomy, including CAVR at present and SLAMR in the future.

Motivation

- Composing and countering super swarms (overwhelming numbers and multi-domain) will require new distributed, real-time algorithms.
- These methods must provide predictable performance, be scalable to large numbers of agents and address the challenges of multi-domain communications, observations and actions.

Deliverables

- New super swarm optimal control formulation for composing and countering large numbers of autonomous agents operating simultaneously above, on and under the ocean.
- Demonstrate the capabilities and limitation of the approach through analysis and experimentation consideration of high value asset protection scenarios

Operational Impact

- As identified by ONR, super swarms present both a risk and an opportunity for a variety of naval operations.
- The proposed analytical and computational methods for composing and countering super swarms generate provable and repeatable performance, which yields the following operational advantages relative to other methods:
  - Commander's intent is mapped directly to all levels of command and control
  - Operator's trust is enhanced by transparent performance predictions for each scenario
  - System test and evaluation feasibility is improved through performance predictions that are robust with respect to scenario conditions

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CRUSER Consortium for Robotics and Unmanned Systems Education and Research

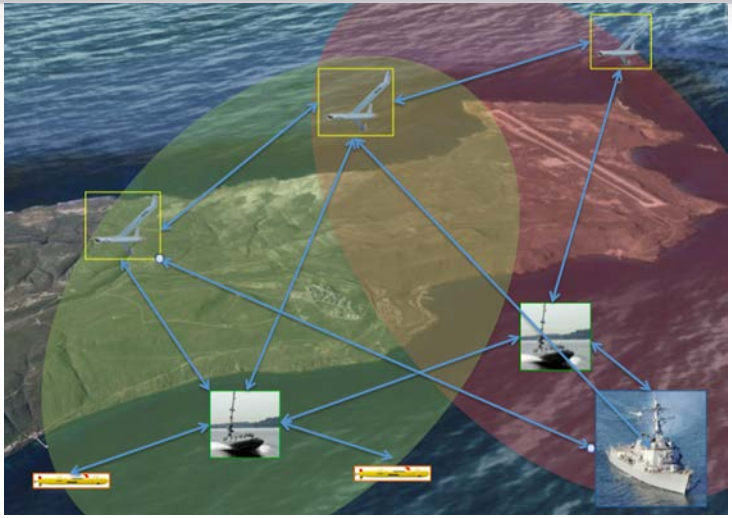
DEPARTMENT OF THE NAVY ONR Science & Technology

Prof. Kaminer, kaminer@nps.edu
Dr. Kragelund, spkragel@nps.edu
Dr. Walton, cwalton1@nps.edu
Prof. Kang, wkang@nps.edu

NAVAL POSTGRADUATE SCHOOL

Multi-Thread Experiment (MTX) (FY17)

CAVR
NPS CENTER FOR AUTONOMOUS VEHICLE RESEARCH



Objectives

- Assemble a network control system (NCS) of networked unmanned aerial, surface, and underwater vehicles (UxVs).
- Develop a venue for collaborative, multi-domain field experimentation under an overarching operational concept.
- Weave multiple research threads into a tactical scenario.
- Explore ramifications of such a system, with emphasis on artificial intelligence, wireless networks, and robotics.
- Develop methods to task UxVs in a hybrid, manned/unmanned NCS to optimally achieve multiple, competing objectives.

Results

- 2-week experiment (San Clemente Island, 10/31-11/15).
- 48 personnel (NPS, SSC-PAC, NSW, NEDU, Reservists, etc.)
- Rapidly deployed a wireless backbone network infrastructure.
- Implemented mobile UxV operational wireless mesh network.
- Integrated 3 UAV, 2 USV, and 2 UUV into the wireless mesh.
- Experiments identified strengths/limitations of the network architecture for supporting expeditionary missions.

- Conducted 4 realistic mission scenarios with NSW and C3F including (simulated) distributed fire support by DDG.
- 5 research initiatives (network analysis, optimal comms relay, optimal UAV search, optimal NCS topology, 3D LIDAR maps).
- UUV IPB survey, USV insert/extract of NSW unit, USV comms relay (UUV-to-UAV), UAV mesh network relay and aerial ISR.
- NSW building search by indoor quadrotor with video relay.

Doug Horner
dphorner@nps.edu
831-656-3821

Alex Bordetsky
abordets@nps.edu
831-656-2287

Sean Kragelund
spkragel@nps.edu
831-656-1159

Aurelio Monarrez
amonarre@nps.edu
831-656-3775

CRUSER

Cooperative Autonomous ScanEagle (FY18)

NAVAL POSTGRADUATE SCHOOL

CAVR NPS CENTER FOR AUTONOMOUS VEHICLE RESEARCH

Motivation

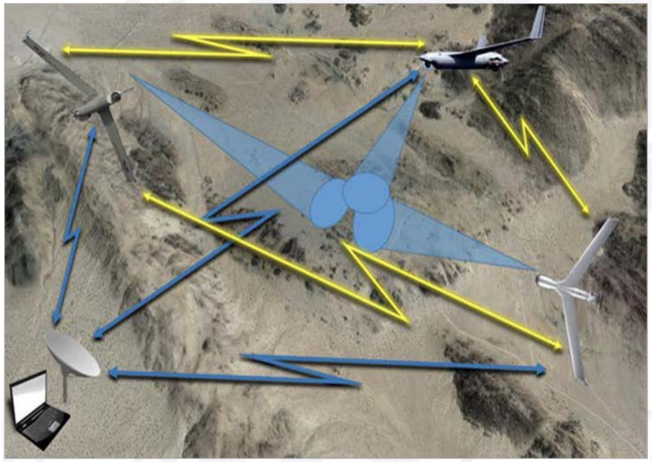
- Naval Special Warfare (NSW) uses ScanEagle UAVs for information operations (IO) and intelligence, surveillance, reconnaissance (ISR).
- Improved autonomy is required to overcome this system's 1-to-1 operator-to-aircraft ratio.
- Distributed, cooperative operations with multiple networked aircraft can improve man/machine teaming, reduce operator workload, and enable enhanced IO and ISR capabilities.

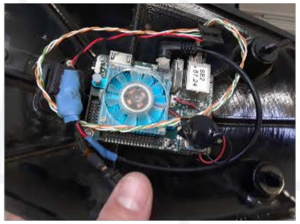
Objectives

- Autonomously task a single ScanEagle UAV using an NPS computer payload (secondary controller).
- Develop the capability to generate and execute non-standard flight trajectories with a secondary controller.
- Enable remote, networked users to initiate blue-force tracking via the ScanEagle's onboard camera turret.
- Partner with Naval Information Warfare Center (NIWC) Pacific and Naval Air Warfare Center Weapons Division (NAWCWD) China Lake for payload integration.

Results

- Flight testing with NSW operators at Camp Roberts demonstrated secondary controller.
- Collected extensive in-flight data of wireless network SNR for communications optimization.
- Successfully flight-tested autonomous control and networked ISR with camera & IO payloads.
- Conducted successful system demonstration with NIWC Pacific and NAWCWD China Lake at Yuma Proving Ground in July 2018.





The econdary controller payload implemented the NPS autonomy architecture for cooperative ISR.

Aurelio Monarrez amonarre@nps.edu 831-656-3775

Sean Kragelund spkragel@nps.edu 831-656-1159

Doug Horner dphorner@nps.edu 831-656-3821

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FATIGUE FAILURE OF FIBROUS COMPOSITES

Dist. Prof. Young W. Kwon, MAE

LCDR Lauren Kadlec, USN; LT Carlos Diaz-Colon, USCG

Multifunctional, Multiphysics, & Multiscale Research Laboratory (M^3 Lab)

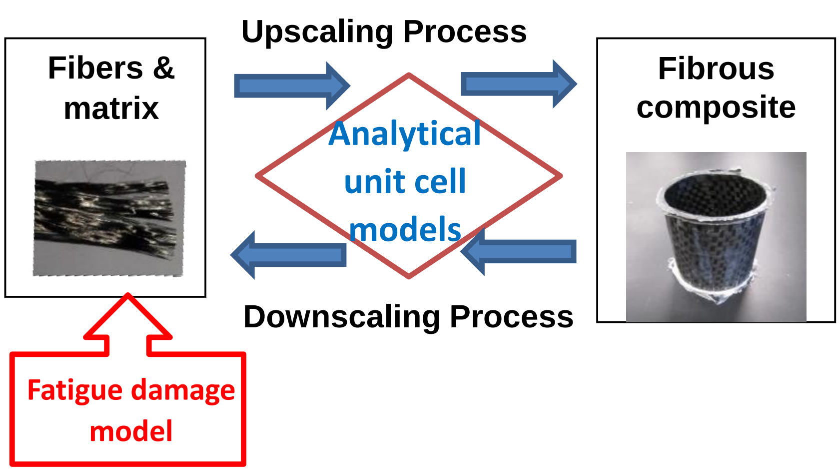
Motivation

To design composite structures for aircraft and ships with reliable prediction of their service life.

Research Objectives

To develop a physics-based model to better understand and predict fatigue failure of fibrous composite materials and structures under multiaxial and multi-cyclic loading using the multiscale approach

Fatigue Failure Models based on Multiscale Approach



PAYOFFS & Expected Outcome

The model will provide the capability for changing various design parameters to understand and predict fatigue failures without extensive fatigue testing, which will save time and money for reliable design of new composite structures.

NAVAL POSTGRADUATE SCHOOL

NPS Total Ship Systems Engineering (TSSE)

Graduate Level Program

- Ship design process using systems approach
- Hosted in the Mechanical Engineering Dept.
- Team capstone project – separate from thesis
- Unique sub-specialty code awarded

Experienced Faculty Team (ME, SE, EE, PHY)

- Interdepartmental / interdisciplinary focus
- Interaction from warfighters, academia and industry
- Program Sponsor (NAVSEA 05)
- Navy operational leaders as stakeholders

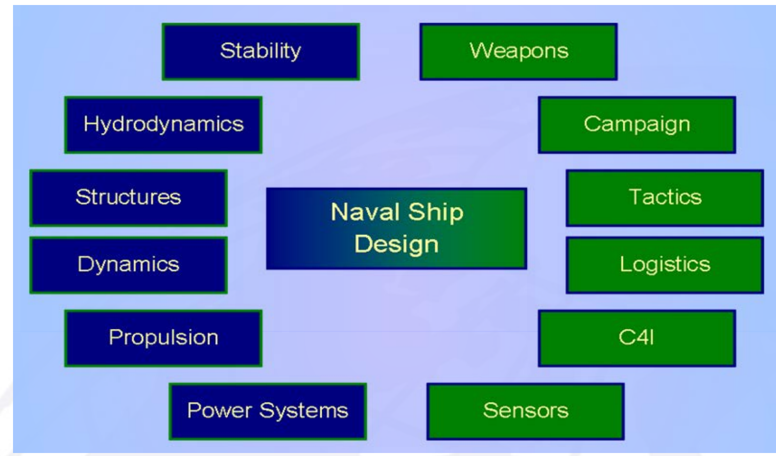
Diverse Student Cohorts

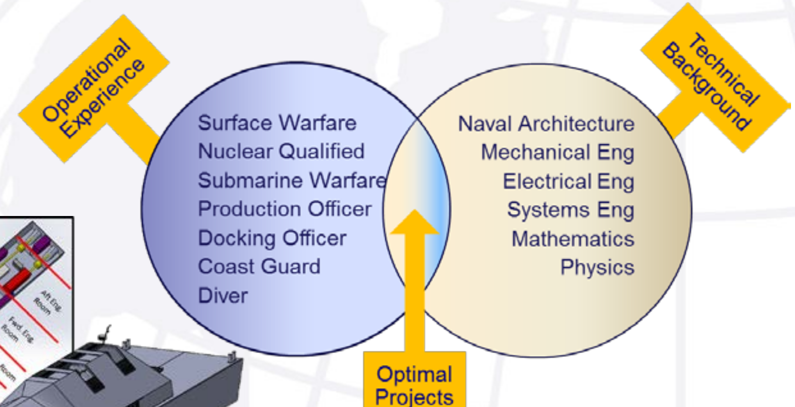
- Multi-curricula, multi-service, multi-national
- Optional study area - In addition to master’s degree

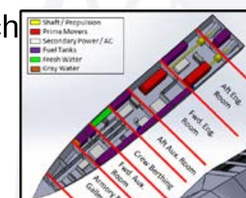
Innovative Results

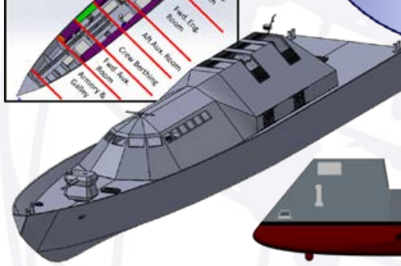
- New perspectives on today’s ship design challenges
- Project concepts lead to further in-depth research

TSSE Program Content









Over 300 NPS TSSE Program graduates since 1992

(Major Program Managers, Shipyard Commanders, Ship Industry Leaders)

Jarema M. Didoszak, Program Director

Mechanical and Aerospace Engineering Dept.

jmdidosz@nps.edu 831-656-2604

STUDY OF UNDERWATER SHOCK LOADING

Dist. Prof. Young W. Kwon, MAE
Research Assist. Prof. Jarema M. Didoszak, MAE

Shock & Vibrations Computational Laboratory

Motivation

Research Objectives

To understand and predict dynamic responses and failures of composite structures subjected to underwater explosion or implosion.

Approaches

Physical experiments will be conducted at an anechoic water tank.
Multiphysics and multiscale modeling and simulation will be also conducted.

Proposed Work

- Use of liquid nitrogen in a container bottle as a source to produce shock pressure as the container ruptures.
- Test rigs to support composite structures in an anechoic water tank.
- Measure pressures and strain responses of composite specimens.
- Conduct numerical studies using the multiscale and multiphysics models.

Test Rig Inserted to Anechoic Water Tank

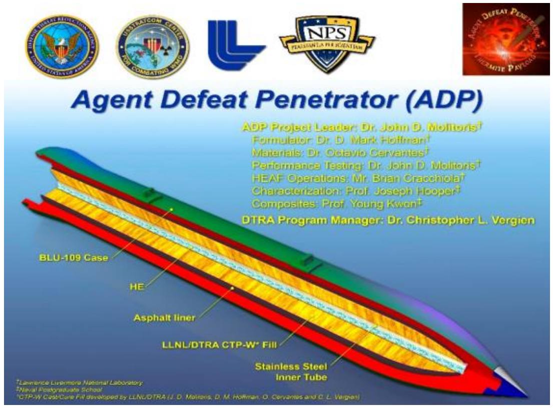
COMPOSITE CASING FOR AGENT DEFEAT PENETRATOR

Dist. Prof. Young W. Kwon, MAE
Stanley Defisher, USARMY CCDC AC

Multifunctional, Multiphysics, & Multiscale Research Laboratory (M^3 Lab)

Motivation

To develop composite casings for high explosive agent defeat penetrator.



Research Objectives

To design and fabrication of composite casing for agent defat weapons

Approaches

Both computational modeling & simulations using a multiscale approach and experimental tests.

High Strain Rate Failure of Composite Materials

- Material failure modeling in terms of constituent materials
- Physical testing with explosives
- Use of Photon Doppler velocimetry (PDV) and high speed cameras to measure and view the deformation of composite cylinders and their failure

Testing with Explosives

FLUID-STRUCTURE INTERACTION OF COMPOSITES

Dist. Prof. Young W. Kwon, MAE

Multifunctional, Multiphysics, & Multiscale Research Laboratory (M^3 Lab)

Motivation

More composite ships…

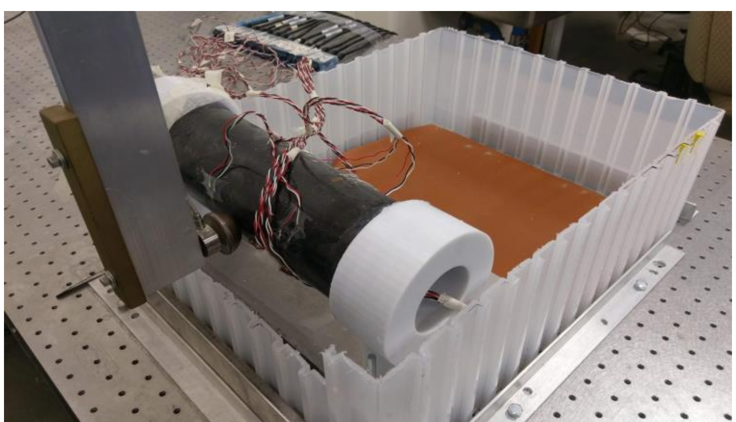
Research Objectives

To study dynamic characteristics of composite structures with Fluid-Structure Interaction (FSI) for naval applications. In particular, this is focused on coupling of composite structures by fluid.

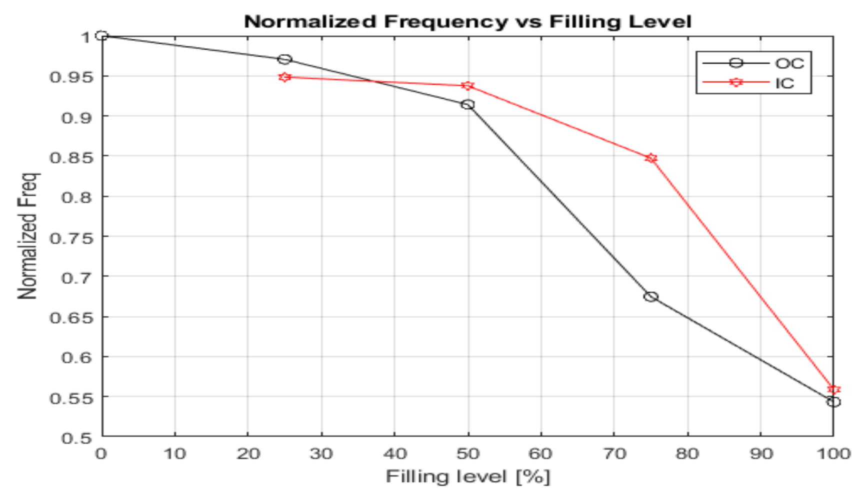
Approaches

Both modeling & simulation using a multiphysics models and physical testing of new designed FSI systems.

Experimental Set-up for Two Concentric Cylinders Containing Water between Them and Subjected to Impact Loading



Change in vibrational frequency as a function of water amount in the annulus

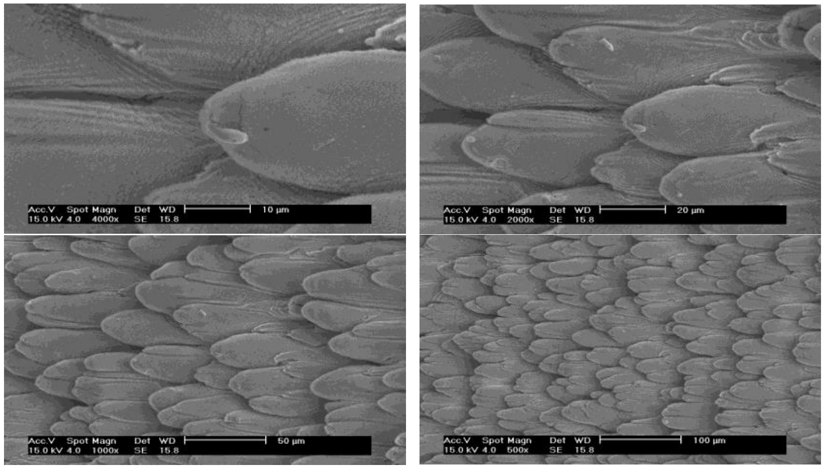


DRAG FORCE OF SUPERHYDROPHOBIC SURFACES

Dist. Prof. Young W. Kwon, MAE
Dr. Chanman Park

Multifunctional, Multiphysics, & Multiscale Research Laboratory (M^3 Lab)

Motivation



Research Objectives

To measure the reduction in hydrodynamic drag forces on superhydrophobic surfaces prepared using the femto-second laser

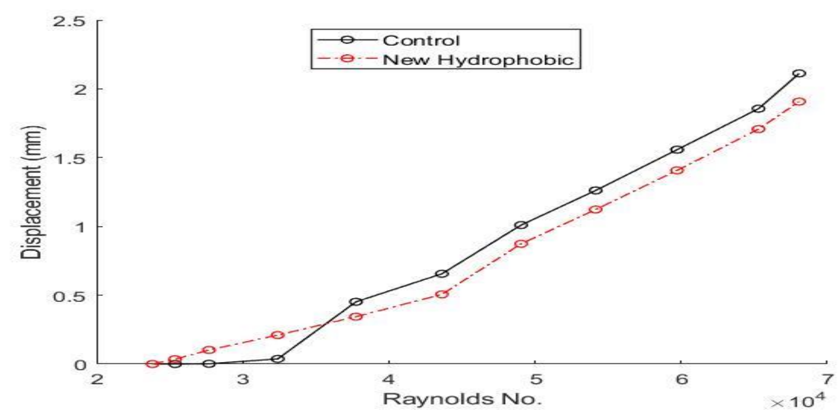
Approaches

Development of a water circulation channel which can measure the hydrodynamic drag force which is in the magnitude of milli-Newton.

Experimental Set-up

Water channel designed and fabricated at NPS (left) and specimens with displacement sensors (right)

Results



Comparison of displacement resulting from drag force between control and superhydrophobic samples.

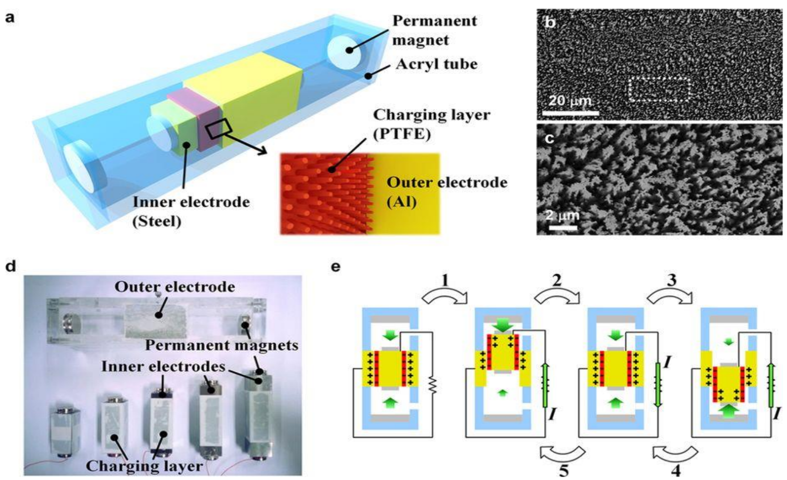
TRIBOELCTRICICITY GENERATION

Dist. Prof. Young W. Kwon, MAE

LT June Capelle, USN; LT John Barmann, USN

Multifunctional, Multiphysics, & Multiscale Research Laboratory (M³ Lab)

Motivation



Research Objectives

To generate electricity from frictional motion of two surfaces resulting from ocean wave or motions of ships and aircrafts.

Approaches

Optimization of parameters to generate the maximum electricity from the frictional motion. Design and fabrication of triboelectric generation systems with applications to the Navy and DoD.

Potential Applications

- Use of ocean wave induced water column system to provide electric power for port security system.
- Use of motion of UAV, USV, and UUV to recharge their batteries for longer operation
- **Multifunctional structures** for energy harvesting, load-carrying structures, etc.

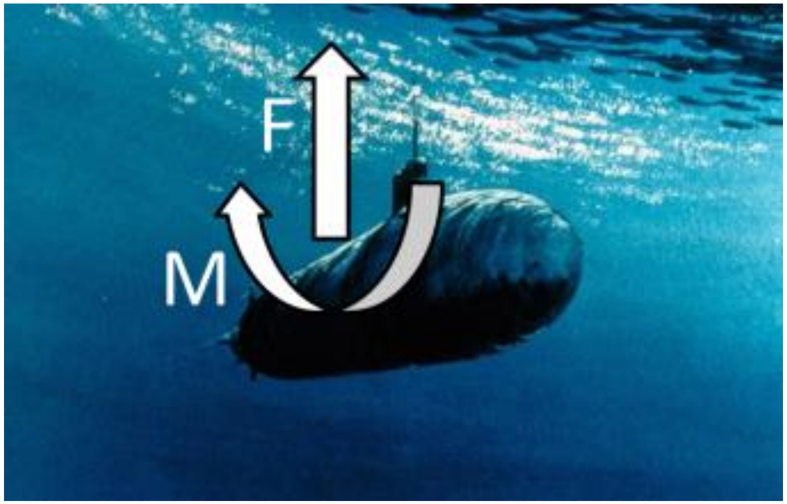
Examples

Navigation of UUV near Surface subjected to Sea Waves

Dist. Prof. Young W. Kwon, MAE
Asst. Prof. Joseph Klamo, System Eng

Multifunctional, Multiphysics, & Multiscale Research Laboratory (M^3 Lab)

Motivation



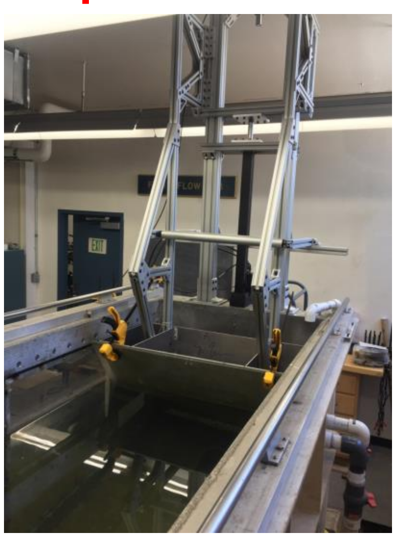
Research Objectives

To study hydrodynamic loads on near surface UUV resulting from the sea waves to maintain the desired course of navigation.

Approaches

Experimental and numerical studies were conducted to measure and compute the resultant forces and moments under different wave loadings

Experimental and Numerical Set-up



Studies Conducted

- Stationary bodies of different geometries
- Moving bodies with constant and varying speeds
- Bodies of different pitch angles (or angles of attack)

Effects of Environmental Factors On Additive Manufactured Materials

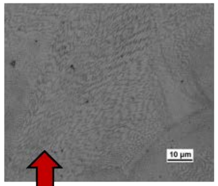
Claudia C. Luhrs, NPS, ccluhrs@nps.edu, 831-656-2568
Troy Ansell, NPS, troy.Ansell@nps.edu (831) 656-3033, LT Josh Ricks

Objectives and Motivation

With the expanding use of additive manufacturing approaches for the fabrication of key parts and components for DoD applications, there is also a growing need to identify the factors that could put the technology at risk. This research aims to determine the effects that humidity, UV light and salt containing environments have in the composition, microstructure and properties of the most common materials used for 3D printing parts.

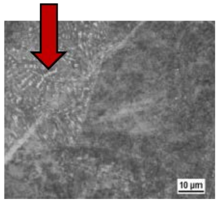
Study case: Maraging steel

Special class of low-carbon ultra high strength steel that derive their strength not from carbon but from precipitation of intermetallic compounds:

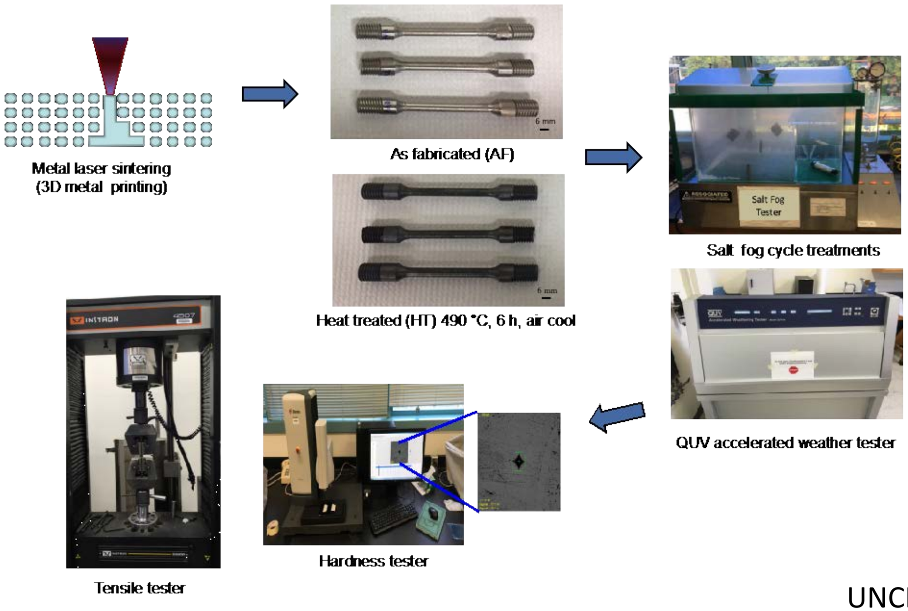


Fe (balance)
Ni (17 - 19 wt-%)
Co (8.5 - 9.5 wt-%)
Mo (4.5 - 5.2 wt-%)
Ti (0.6 - 0.8 wt-%)
Al (0.05 - 0.15 wt-%)
Cr, Cu (each ≤ 0.5 wt-%)
C (≤ 0.03 wt-%)
Mn, Si (each ≤ 0.1 wt-%)
P, S (each ≤ 0.01 wt-%)

	Austenite γ	Martensite α
As-produced	5.8%	94.2%
Age hardened 480°C, 5h	9.4%	90.6%



Graphical abstract



Tasks and approach

Identify which variables could affect the lifetime of an object to allow stakeholders to identify failure modes and use realistic estimates regarding when to supply new ones.

- The experimental work will consist of salt-fog and accelerated weather treatments of 3D printed specimens (metals, composites and polymeric parts).
- Evaluation of mechanical properties and microstructural changes using diverse techniques.
- Comparison of behavior of parts produced by traditional approaches (CNC).

Evolution of Raw Powder Characteristics Through the Metal Additive Manufacturing Reuse Cycle

Claudia C. Luhrs, NPS, ccluhrs@nps.edu, 831-656-2568
LT Sam Murphy

Background

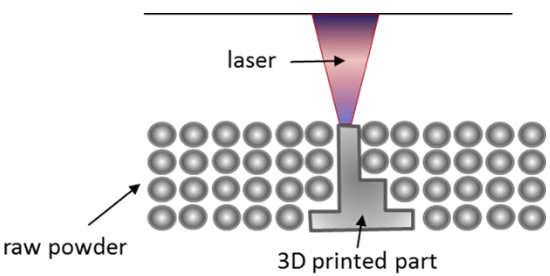
Powder bed fusion additive manufacturing (PBFAM) is one of the common techniques used to 3D print metals and alloys. The process involves the use of a laser to join individual particulates (raw powders) and create a complex part layer by layer.

Advantages of metal AM:
Complex alloy parts can be fabricated
Relatively short time
No tooling required
Optimal amount of raw material

Example of part required

Problem description

During the 3D fabrication steps certain regions of the powder interact directly with the laser beam and finish being part of the solid produced, however, adjacent particles that do not become a section of the build, are still exposed to higher temperatures and to the printing environment. In order to deliver the cost savings expected from this fabrication method, the powder that remains in the printing bed should be reused.

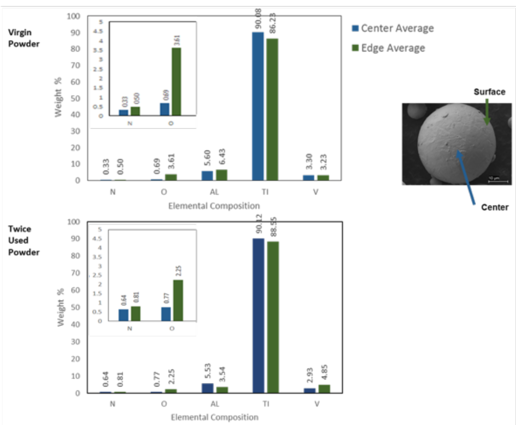


Objectives and Motivation

This study aimed to determine if the characteristics of Ti6Al4V powder that remained in the PBFAM system changed after some reuse cycles. Solids made from virgin and reused powders were also analyzed and compared.

Approach and findings

Evidence of sintering and of particle breakage / new particle formation. Effective particle size control achieved through sieving.



Chemical composition: Particulate surface richer in oxygen and nitrogen than the center. Enrichment of nitrogen in surface through reuse.

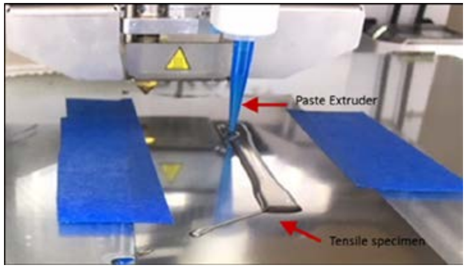
Nanoparticle Based Alternative for Metal Additive Manufacturing

Claudia C. Luhrs, NPS, ccluhrs@nps.edu, 831-656-2568
LT Farsai Anantasilip, Richa Agrawal and LT Gabriel Supe

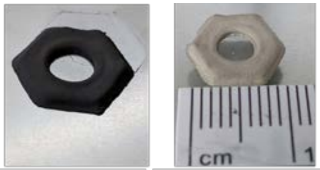
Objectives and Motivation

We aimed to produce metal or alloy parts through the use layer-by-layer extrusion of small particle paste formulations using a polymeric printer along post-processing steps (anneal/HIP). This new approach is meant to greatly reduce costs and make metal additive manufacturing (AM) more accessible to operational sites.

Graphical abstract

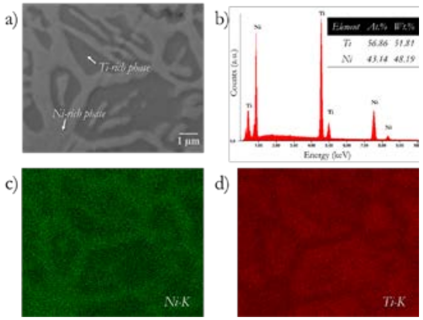


Sinter / HIP



"Green" Product after 3D printing

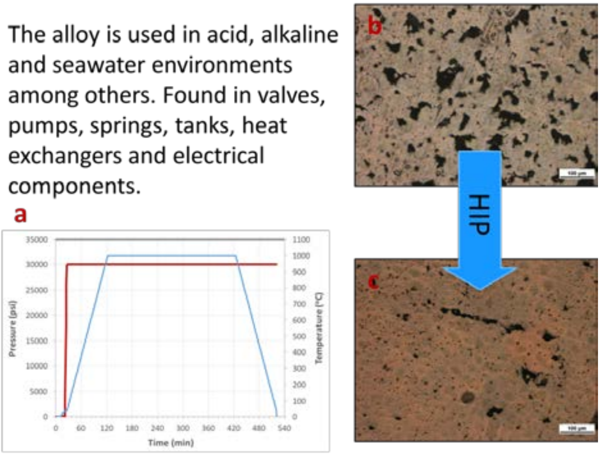
Part after post-process HIP Testing



Study cases

NiCu alloy. Monel.

The alloy is used in acid, alkaline and seawater environments among others. Found in valves, pumps, springs, tanks, heat exchangers and electrical components.



a) NiCu specimens were hot isostatically pressed at 1000 ^{0}C at diverse pressure conditions.

b) Porosity and gran structure of specimens pressed at 20,000 psi and c) 25000 psi.

d) Metallographic specimen of NiCu HIP at 25K psi.

Findings and future work

Demonstrated that the new process could successfully generate solid specimens, which, after HIP operations, showed mechanical robustness. This new approach could be easier to adapt than laser or e-beam sintering routes and could be applied for metal/alloy parts that do not require stringent load bearing specifications.

Next steps include the fabrication of complex shapes and treatments at higher HIP pressures/temperatures.

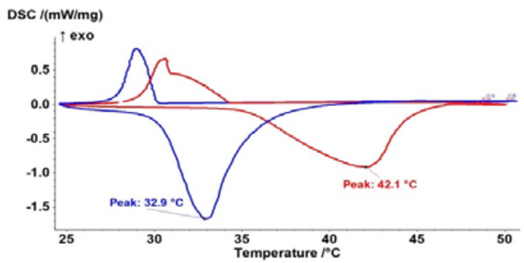
Epoxy - PCM formulations to improve thermal performance of living and storage spaces

Claudia C. Luhrs, NPS, ccluhrs@nps.edu, 831-656-2568
ENS Joshua Hanna, Dr. Richa Agrawal

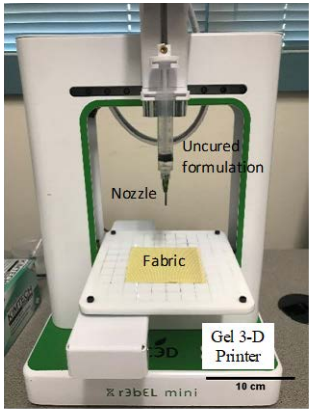
Background

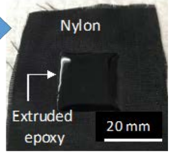
The term Phase Change Material (PCM) refers to substances capable to store and release energy when the material changes from solid to liquid and vice versa.

PCMs have great potential to be used for thermal energy storage purposes, however, formulations need to be optimized to comply with the thermal-physical, kinetic, chemical and cost requirements.



Tasks and approach





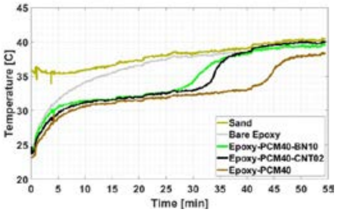
Testing:
DSC
Thermal conductivity

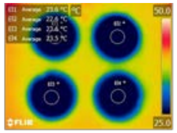
Objectives and Motivation

In the military context, finding a way to control the temperature of living and storage spaces using PCMs will result in energy savings since it will allow the use of smaller HVAC equipment while keeping indoor temperatures within a comfortable range.

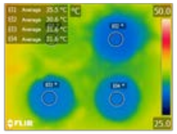
Milestones

- Identified applicable PCM with high latent heat of fusion, repeatability and near room temperature melting point.
- Successfully developed a formulation and fabrication process which allows for a homogeneous mixture of Epoxy-PCM at high loading.
- Thermal properties and effects of including thermal additives (BN,CNT) were found using DSC techniques.
- Incorporated PCM-Epoxy system into fabric through use of gel 3D printer.
- Thermal imaging, specific heat and thermal conductivity comparison of diverse formulations has been conducted to help identify the best thermal additives.

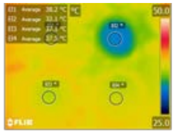




Infrared Image immediately after samples placed into sand.



Infrared Image after 15 minutes. Bare Epoxy at thermal equilibrium.



Infrared Image after 35 minutes. Thermal additive formulations at thermal equilibrium.

Study of Fundamental Limits of Carbon Nanotube (CNT) Composites for Space Applications

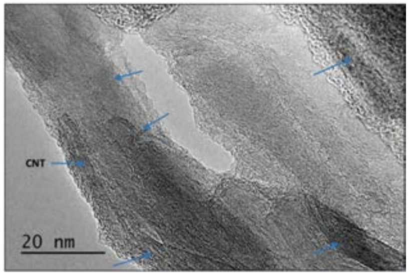
Claudia C. Luhrs, NPS, ccluhrs@nps.edu, 831-656-2568

Objectives and Motivation

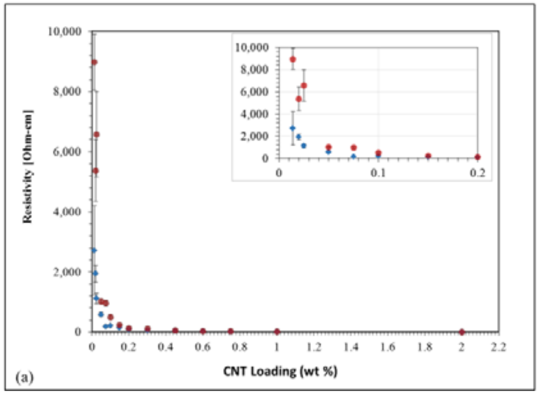
Experimental research conducted at the Naval Postgraduate School, in collaboration with Nanocomp Technologies Inc. and Craytex LLC, aims to:
i) identify the mechanisms responsible for the high electrical conductivities encountered in CNT composites with low CNT loadings, ii) determine to which extent the electrical and mechanical properties can be tailored by the fabrication routes, iii) develop strategies to improve those and iv) study failure modes that can be expected under extreme conditions.

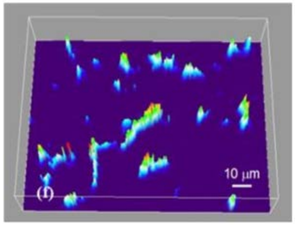
Expected Results - Benefits

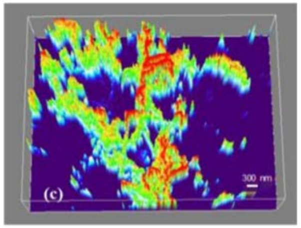
Light weight CNT-based technologies are already part of the backbone of the DoD space enterprise, from their use as structural materials to applications related to their electrical conductivity, such as charge dissipation and electromagnetic shielding.
Knowledge of the basic mechanisms responsible for their properties under extreme conditions (high temperatures, high currents, high frequencies, etc.) could enable us to tailor their microstructures and provide the groundwork from which other revolutionary concepts and technologies can be developed.



Graphical Abstract







Tasks

Corroborate the electrical properties observed by industry partners in their samples. Analyze samples by diverse characterization techniques to create a baseline for both, the individual components and the composites at the loadings provided.

Fabricate samples at NPS to demonstrate repeatability in the electrical measurements using known protocols.

Determine the influence of particular dispersion and fabrication steps, CNT loadings, the use of diverse CNT batches, curing temperatures/times, etc.

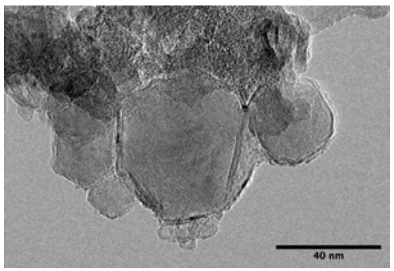
Generate a model to explain the conduction mechanisms based on literature data and information gathered from the analysis of the samples.

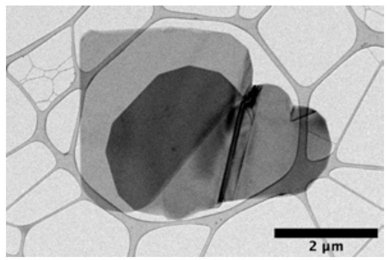
Cold Sprayed Aluminum Composite Coatings with Dual Nanoparticle Reinforcements for Enhanced Wear & Corrosion Resistance

Prof. Andy Nieto , andy.nieto@nps.edu
Student: LT Travis Norrell

Motivation and Objectives:

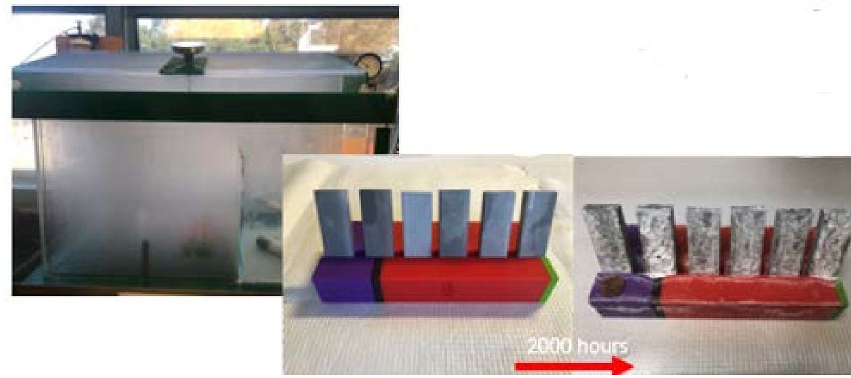
- Cold spray is an additive manufacturing technique being introduced into the field for structural and dimensional repairs of metallic components
- Ease-of-use and scalability make cold spray an attractive technique for developing new materials with superior properties such as wear resistance in order to improve durability and reduce sustainability costs





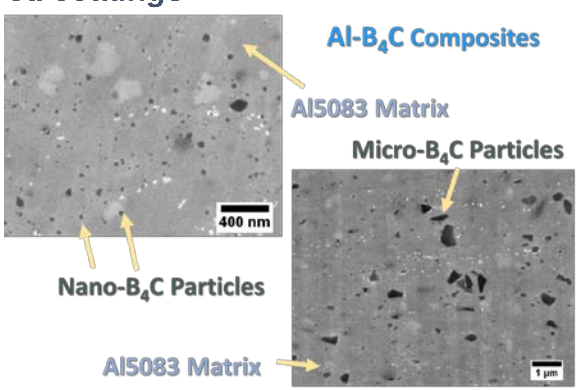
Experiments:

- Aggressive simulated marine corrosion experiments are conduced, followed by materials microanalysis



Technical Concept:

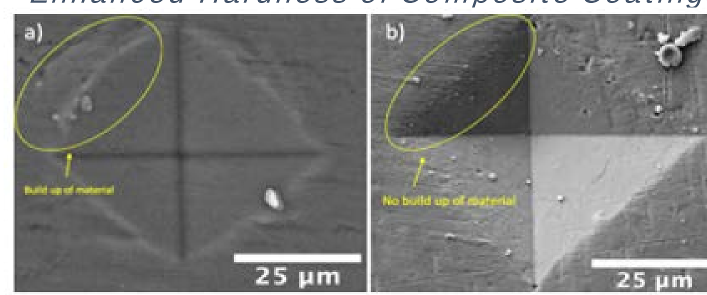
- The use of dual nanoparticle reinforcements to provide a synergistic reinforcement effect has received minimal exploration – ***and none in the field of thermal or cold sprayed coatings***

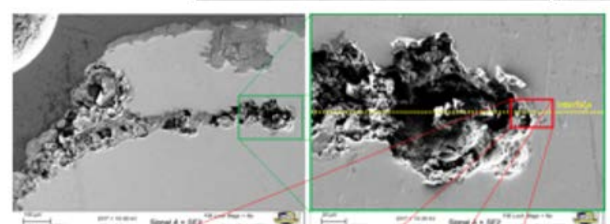


Nieto, A., *Wear*, 2018, pp. 228-235

Outcomes

Enhanced Hardness of Composite Coatings





Retention of Al Corrosion Resistance

Investigation of Cold Sprayed Deposit Adhesion on Dissimilar Materials

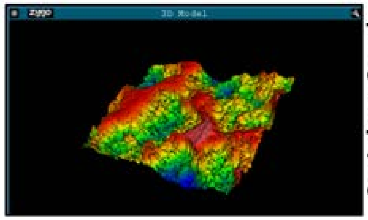
Prof. Andy Nieto , andy.nieto@nps.edu
Student: LT Jeffrey Mitchell

Motivation:

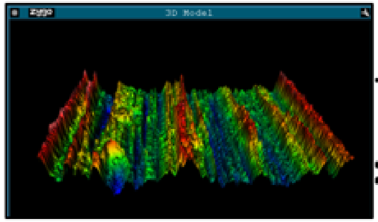
- Cold spray is a scalable materials processing technique suitable for surface repair and corrosion prevention applications.
- Studies on cold spray have been largely limited to magnesium and aluminum substrates, other important naval materials such as brass, steel, and copper have received limited study
- Optimization of deposit adhesion and strength/hardness is critical to the widespread implantation of cold spray for ***structural*** repairs.

Objectives:

- A systematic investigation into parameters controlling adhesion strength and hardness of cold spray coatings will be conducted on various substrates of naval relevance
  - Steel
  - Magnesium
  - Aluminum
  - Copper
- Effect of surface roughness and particle distribution to be quantified



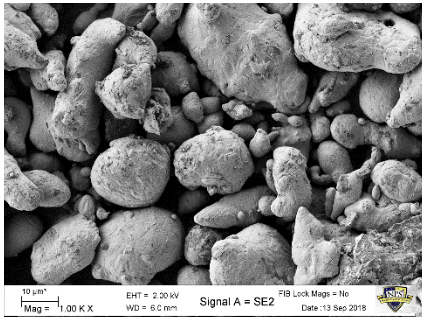
Stainless Steel

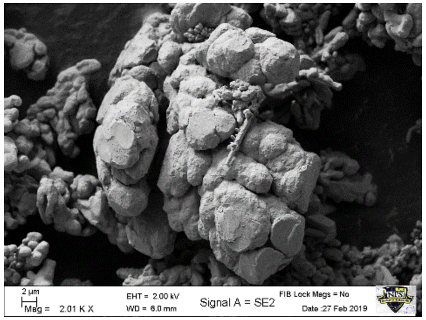


Magnesium

Technical Challenges:

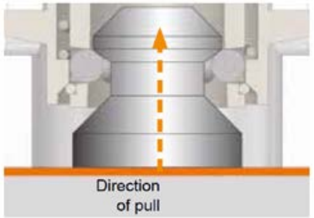
- Feedstock powders exhibit a wide range of morphologies and sizes - ***the effect of these variables on hardness and adhesion are poorly understood***
- Substrate finish has been a subject of debate – *are there substantial benefits of surface cleaning on cold spray deposit adhesion?*

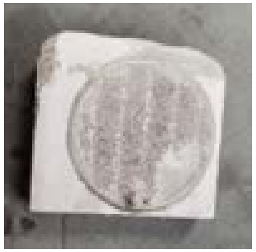




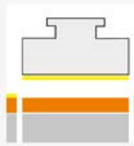
Experimental Approach:

Schematic of Adhesion Test





Adhesion Failure Modes



Adhesive Failure

Coating Failure

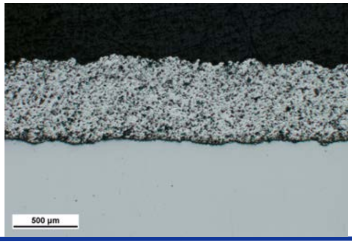
Partial Coating Failure

Effect of Cold Spray Coating Thickness on Corrosion Behavior

Prof. Andy Nieto , andy.nieto@nps.edu , Prof. Troy Ansell, troy.ansell@nps.edu
Student: LT Latriva Johnson

Motivation & Objectives:

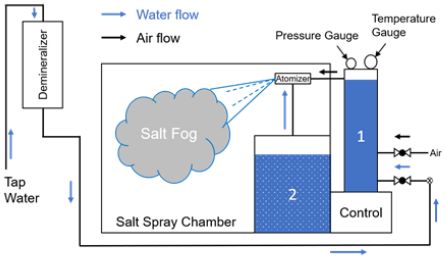
- Understand the role of coating thickness on corrosion behavior
- Results will guide how stakeholders such as NAVSEA determine how thick a coating is needed for repairs in corrosive marine environments



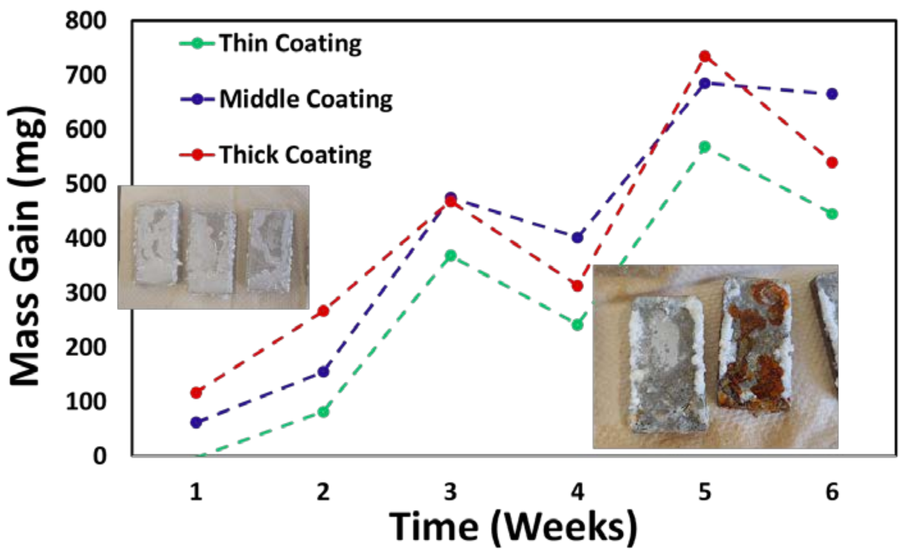
Experimental Methods:

- Cold spraying with nitrogen gas was used to deposit Al-Al_2O_3 coatings with coating thickness ranging from ~100 µm to 2.5 mm, on HY100 steel
- Microstructures and corroded specimens evaluated by SEM, OM, XRD

Schematic of Salt Fog Testing

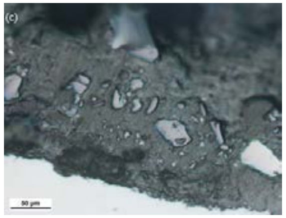


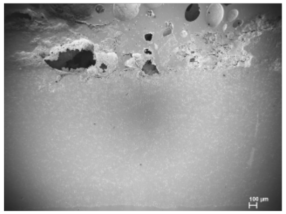
Corrosion Data:

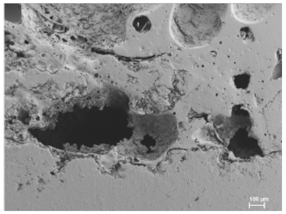


Outlook & Ongoing Work:

Pitting Corrosion







- Pitting corrosion seen in all coatings, in thick coatings pits are as deep as ~500 µm
- Thin coatings are destroyed with only a few coating remnants embedded in oxide products
- Pure Al coatings to be investigated and testing on CuNi substrates is ongoing

Additively Manufacturing Metal Matrix Composites by Selective Laser Melting

Prof. Andy Nieto , andy.nieto@nps.edu
Students: ENS Andrew Reinhart, LT Anthony DeMartino, LT Marian Jester

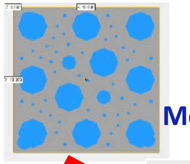
Motivation and Objectives:

- Additive manufacturing has great potential for Naval applications and enabling manufacturing at the point of need.
- New materials must be developed using new AM techniques to enable rapid technology transition
- Metal matrix composites enable attainment of materials by design for use in extreme environment applications

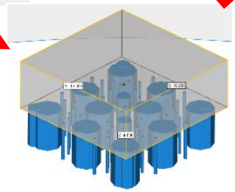
EOSM100 Printer

3D Printing Process:

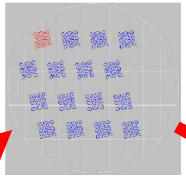
- Specimens suitable of oxidation studies, simulated marine corrosion, impact testing, and materials analysis are produced.



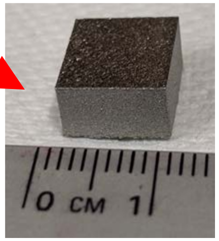
Cylindrical Supports for Metal 3D Printing



Sliced CAD Model on Supports



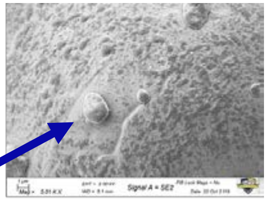
Bulk 3D Printed Ti64-Oxide Composite



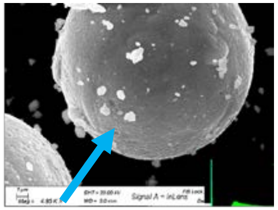
Novel Powder Synthesis:

- Ti64 Powder with aluminum oxide, tantalum oxide, cerium oxide, boron nitride nanoplatelets, and carbon nanotubes have been developed in our lab

Arrow Points to Oxides Attached to Ti64 Base Powder

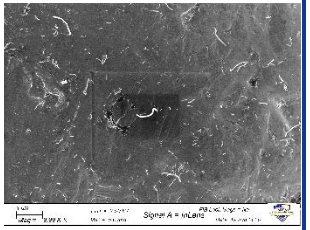


Ti64-Al_2O_3



Ti64-Ta_2O_5

Embedded Carbon Nanotubes

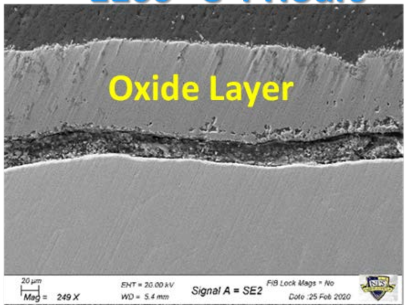


Ti64-CNT

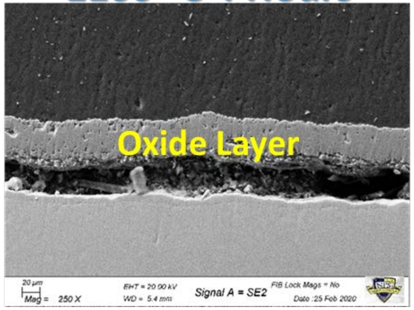
Outcomes

Enhanced Oxidation Resistance at 1100 C

Ti64 (Control Sample) 1100° C 4 Hours



Ti64-Ta_2O_5 1% 1100° C 4 Hours



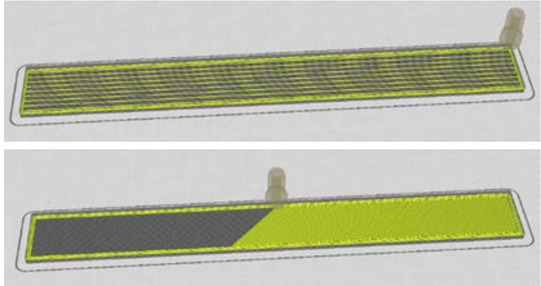
Mechanical Behavior of 3D Printed Polymers and Polymer Matrix Composites

Prof. Andy Nieto , andy.nieto@nps.edu , Prof. Young Kwon , ywkwon@nps.edu

Students: LT Michael Pizzari, LT Charles Hodgkins

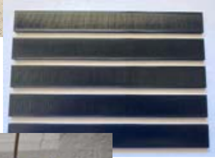
Motivation & Objectives:

- Quantify role of printing orientation, print pattern, and layer thickness of mechanical properties
- COMSUBPAC has interest in installing Lulzbot Mini FDM printer in submarines and requires best practices on parameters and evaluation of potential use for permanent or structural load-bearing points



Materials Printed:

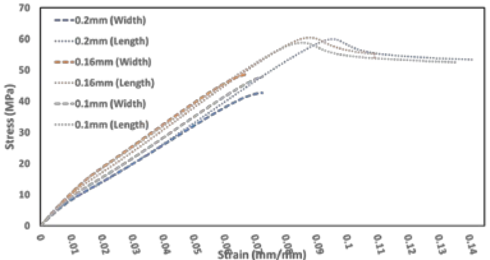
- PLA – most commonly printed material for FDM polymer printing
- PETG – Recyclable thermoplastic with high strength and heat resistance
- Polycarbonate – high toughness polymer that can be made transparent
- PLA-Bronze – PLA infused with ~10 volume % bronze particulates
- PLA-Steel – PLA infused with steel particulates



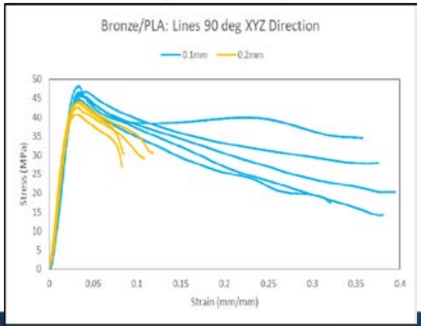
Mechanical Behavior:

- Thinner layers (0.1 vs 0.2 mm) generally yield greater strength and toughness
- Linear patterns yield greatest properties, most effective when bead/fiber lines are aligned with loading direction

Aligned beads (fibers) yield greater strength



0.1 mm Layer thickness yield greater tensile strength and rupture strain



Summary & Future Work:

- PET has greater strength/toughness than PLA
- Concentric printing pattern yields greatest compressive strength
- Further work need to characterize dynamic mechanical properties (fatigue & wear)
- Must evaluate deterioration under UV/humid environments
- Comparisons underway between steel and bronze reinforcements in PLA

Spacecraft Robotics Laboratory

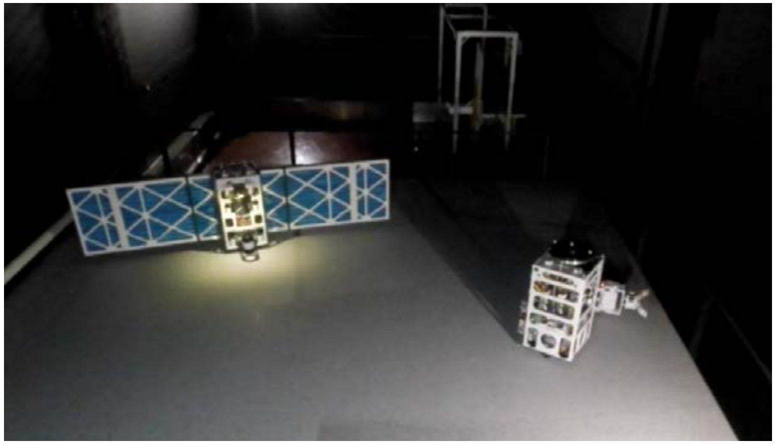
NAVAL POSTGRADUATE SCHOOL

Expertise
- Astrodynamics, GN&C

Ongoing projects
- Robotic capture of a tumbling object
- Experiments on International Space Station
- Optimal orbital maneuvers

Success metrics
- 9 PhD & >40 Ms Graduated
- 57 Journal Articles,
- 8 Patents
- 6 alumni are faculty in US institutions

Experimental Facilities



Approach
- Theoretical and analytical development
- High-fidelity modeling and simulations
- Experimental Testing (in lab and in space)

Marcello Romano
Founder & Director (since 2004)
mromano@nps.edu

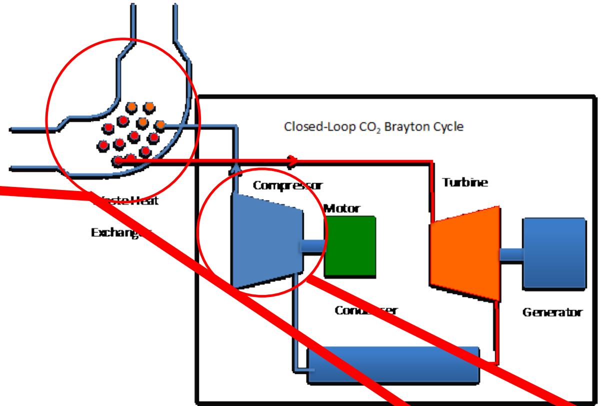
Jennifer Hudson
Deputy Directory (since 2020)
Jennifer.hudson@nps.edu

Waste Heat Recovery From Gas Turbine Exhaust

Prof. Garth Hobson, Doug Seivwright
Students LT Aaron VanDenBerg, LT Coria Buck, LTJG Michael Kaim

Marine Propulsion Laboratory

Waste Heat Recovery System



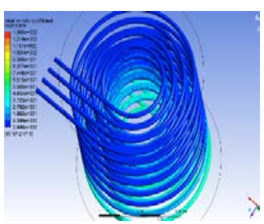
Integrated Electric Gas Turbine Concept

Background/Objective

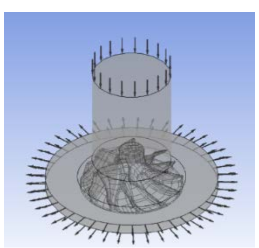
- Gas Turbine thermal loss ~50-55%
- Develop waste heat recovery system to harness this resource
- Increase efficiency in recovery of heat utilizing organic working fluids (CO_2)
- CO_2 Non-Corrosive

Approach, Analysis and Design

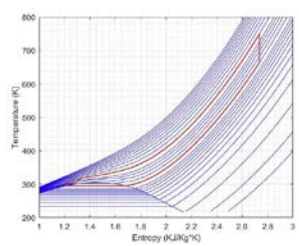
- Analysis of Organic working fluids to harness low quality waste heat.
- Develop Organic closed loop system
- Evaluation of efficiency of the combined system (Gas Turbine and Waste Heat Recovery)



CFD Modeling to minimize backflow pressure on engine while maximizing heat transfer of heat exchanger



ANSYS modeling of CO_2 Compressor



Cycle Analysis using CO2 as Medium

Summary

- Brayton loop construction completed
- Heat Exchanger and CO2 compressor designed and manufactured in house.