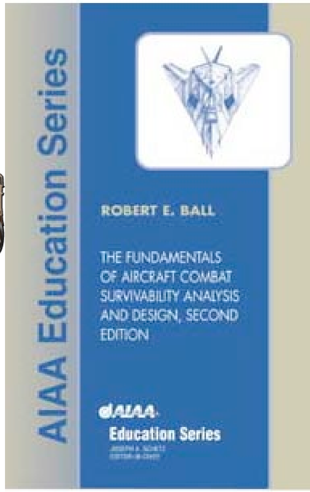
NAVAL POSTGRADUATE SCHOOL

DEPARTMENT OF
MECHANICAL AND AEROSPACE ENGINEERING
RESEARCH PORTFOLIO 2021

Naval Postgraduate School

Center for Survivability & Lethality (CSL)
Aircraft & Ground Vehicle Survivability [Christopher Adams]

NAVAL POSTGRADUATE SCHOOL
CENTER FOR SURVIVABILITY & LETHALITY (CSL)



How

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

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

What

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.

NPS students are warfighters, and consequently they bring a level of knowledge, experience, and judgment to their research that is not available anywhere else

Why

- **Enhanced Operational Effectiveness!**

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**

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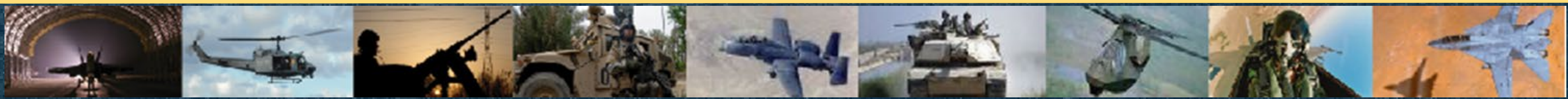

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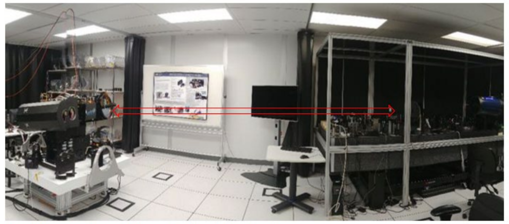
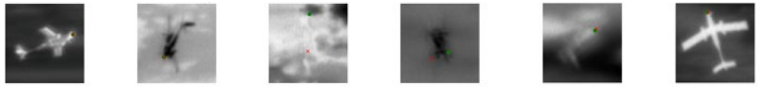
Applications of Artificial Intelligence for High Energy Laser (HEL) Systems

Navy's Laser Weapon Systems (LaWS)



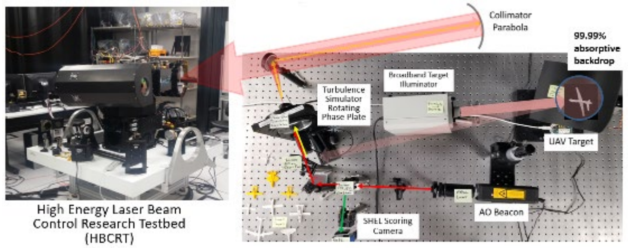
NPS Testbed for HEL Beam Control



Autonomous targeting and aimpoint maintenance

How

- Generation of representative dataset for autonomous targeting and aimpoint maintenance for high energy laser systems
- Apply and develop artificial intelligence and deep learning algorithms for autonomous targeting and aimpoint maintenance
- Implementation of AI algorithms to the NPS HEL Beam Control Research Testbed (HBCRT) to test and demonstrate the proposed end-to-end automatic targeting approaches



High Energy Laser Beam Control Research Testbed (HBCRT)

What

- Autonomous targeting and aimpoint maintenance for high energy laser systems requires detection to locate targets against potentially cluttered backgrounds, classification to identify the target type and select the appropriate aimpoint, pose determination to map aimpoints as the target undergoes 3D pose changes, and tracking and atmospheric turbulence compensation for high-speed line-of-sight stabilization and effective engagement.
- The objective of this research is to evaluate and apply state-of-the-art Artificial Intelligence (AI) techniques for automatic targeting, aimpoint selection, tracking, and adjustment for atmospheric conditions.
- Artificial Intelligence (AI) approaches using state-of-the-art deep learning are valuated and developed for HEL automatic targeting, aimpoint selection, and maintenance problems.

Why

- The proposed effort will be applicable to all DoD services where automatic targeting, aimpoint selection, aimpoint maintenance, and tracking can provide timely and valuable decision aid and enhanced overall performance of HEL systems with reduced engagement time and greater lethality on target.
- Our research will also train many military and civilian graduate students and researchers in this important area and will impact the success of DoD programs.

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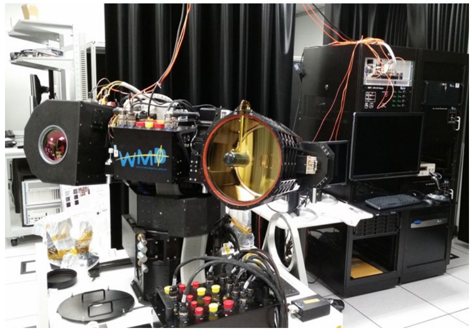
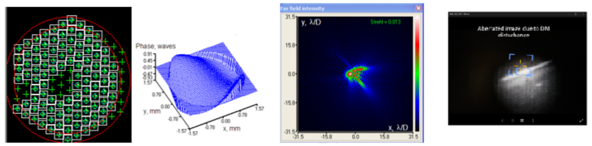
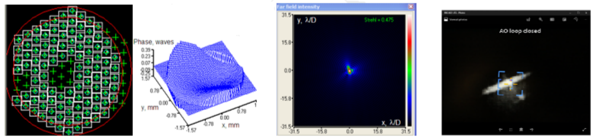
Advanced High Energy Laser (HEL) Beam Control Methods with Integrated Beam Control Experiments



NPS HEL Beam Control Research Testbed (HBCRT)



Uncompensated HEL Beam and Target Image



Compensated HEL Beam and Target Image

How

- Development of advanced adaptive optics technologies that can compensate deep atmospheric turbulence effects. The technology includes the use of fast real-time deformable mirror system and advanced wavefront sensors.
- Applying the state-of-the-art deep learning algorithms and modern control techniques for deep turbulence compensation problems.
- Implementation and evaluation advanced AO and beam control methods using the NPS High Energy Laser Beam Control Research Testbed (HBCRT)

What

- High Energy Laser (HEL) beam control is the critical enabling technology for directed energy systems. The Navy has unique challenges in HEL beam control due to the deep atmospheric turbulence effects caused by the long horizonal HEL beam path over the maritime environment.
- The deep turbulence significantly limits the HEL propagation range and degrade the effectiveness of the directed energy systems.
- The objective of the project is to develop adaptive optics and beam control methods that are effective for deep turbulence conditions for Navy’s directed energy systems and to demonstrate these techniques using the NPS High Energy Laser Beam Control Research Testbed (HBCRT).
- Another objective is to apply artificial intelligence (AI) based beam control methods to simplify and automate HEL systems and provide deep turbulence compensation from target imagery to achieve a beaconless system.

Why

- Tactical missions for HEL systems will require the ability to image and track targets in deep turbulence and precisely point and compensate the wavefront of the outgoing HEL beam. There are many applications that face the challenge of deep atmospheric turbulence compensation. These include mobile defensive systems engaging targets near to the ground, ship borne defensive systems against small boats, cruise missiles, low flying Unmanned Aerial Vehicles (UAVs), tactical systems such as advanced laser fighter aircraft at lower altitudes, directed energy weapons systems such as the ABL over a very long path, and laser-com systems operating over long distances.
- This effort should have significant impact in the improvement of performance of these DoD missions with specific payoff in increased range of operation, reduced SWaP.

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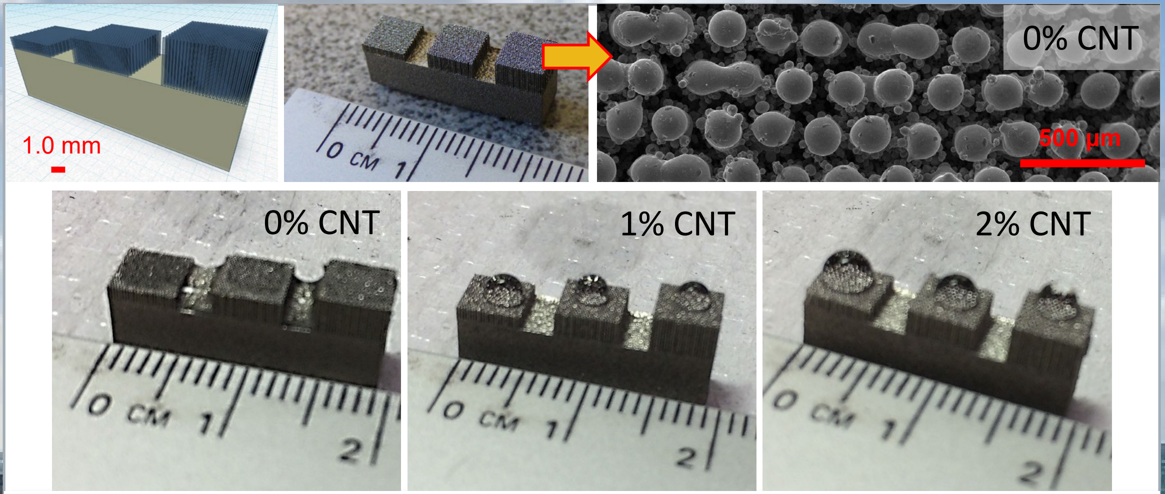
Engineering Superhydrophobic Surfaces by Additive Manufacturing



Top row from left to right: TinkerCAD model of part with three arrays of pillars, 1.0, 2.0, and 3.0 mm in height; image of 3D-printed model; SEM image of top of pillars. Initial wetting experiments conducted on printed samples from left to right: 0 % carbon nanotubes (CNT), 1 % CNTs, and 2% CNTs.

Methodology

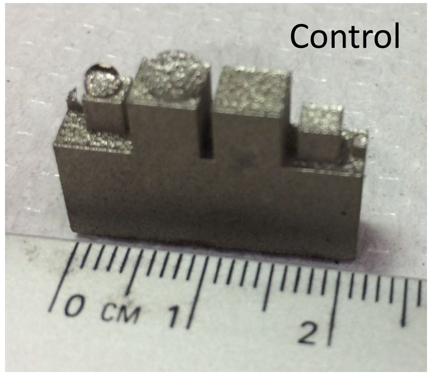
- Superhydrophobic surfaces have been developed using polymers, ceramics, and even metallic coatings. The processes; however, are complicated, expensive, and/or dangerous e.g., some methods use flurosilanes to activate superhydrophobicity of a protective surface.
- Our approach is to instead print arrays of high aspect ratio pillars. The pillars would be printed out of the same material as the main part, stainless steel 316L in this case.
- Samples are printed using the EOS M100 3D metal printer in Watkins Hall.
- The pillars were modelled to be 100 μm x 100 μm x h, where h will be either 1 mm, 2 mm, or 3 mm. Ideally, h should be upwards of 10 mm or the other dimensions closer to 1 μm.
- A limitation in the printer resolution is reached; however, at 100 μm. To get around this limitation and ensure hydrophobic surfaces, carbon nanotubes (CNTs) will be added to the metal powder and printed into the structure.

Background/Motivation

- The DOD and the Navy always has had a need to mitigate corrosion. For FY18, the estimated cost due to corrosion to the DOD was ~ $21 Billion.
- With increasing corrosion related costs of an aging fleet and associated system sustainment and maintenance, that need is increasing.
- With the advent of AM technologies, new strategies for protecting metallic surfaces have arisen.
- Can a 3D printed surface be engineered to resist corrosion by keeping water away from wetting the surface?
- We seek to mimic the hydrophobicity of a lotus leaf in a metal like stainless steel (SS) to improve corrosion resistance and long-term life of the metal.

Operational Impact

- Without CNTs, the SS pillars were not able to hold up a water droplet ~ 3 – 4 mm in diameter, as seen in the lower left-hand image marked “0% CNT.”
- When 1 wt% CNTs were added, the pillars were able to support water droplets as seen in the lower middle image.
- Additional CNTs appear to slightly increase the hydrophobicity of the pillars.
- Image to the right is a SS sample with bulk monolithic pillars serving as a control. The shape of the droplets indicates more wetting occurring without CNTs.



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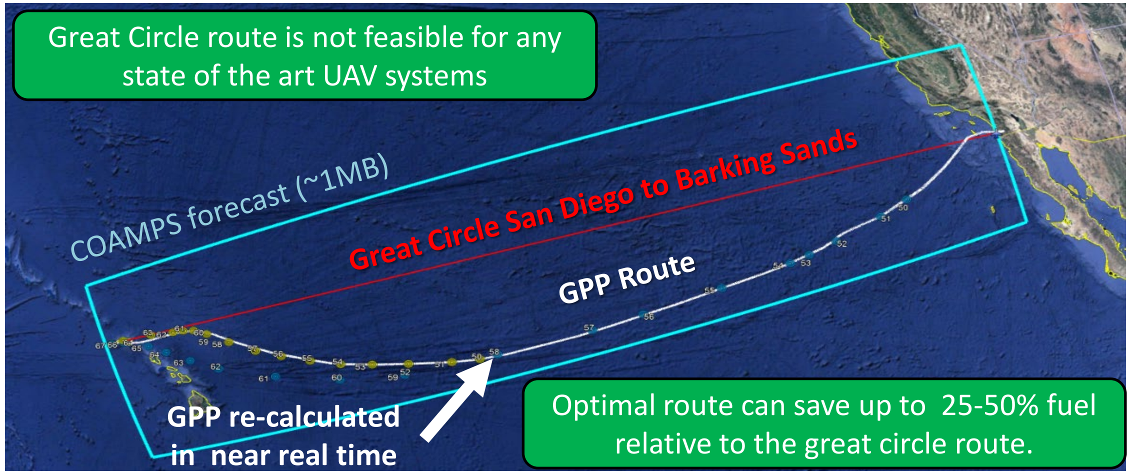
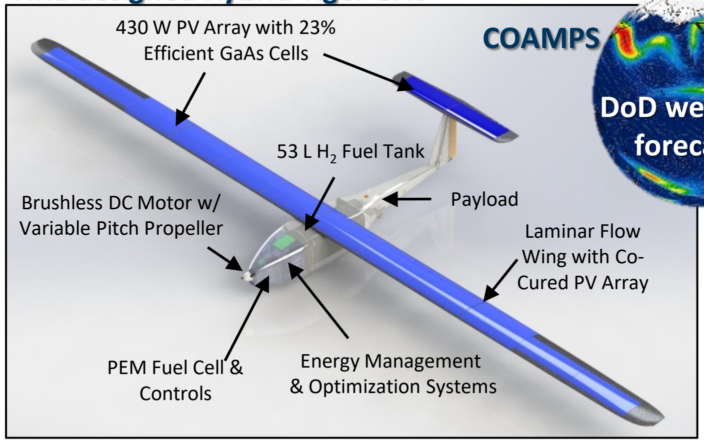
Energy-Aware Autonomy of Group 2 UAS Utilizing Environmental Energy Sources



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

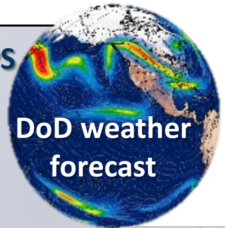
- **Objective** – advance operational energy strategy:
  - Increase current and future UAV capability via adaptable use of various sources of energy.
  - Enhance current mission effectiveness via predictive energy forecast and optimal routing.
  - Identify and reduce risk of energy shortage via robust adaptive mission replanning and intelligent control.
- **Concept** – demonstrate 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

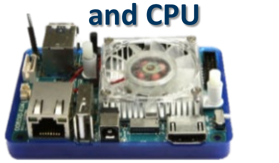


Patent: U.S. PTO 16/155,968, U.S. PCT PCT/US18/55144

COAMPS



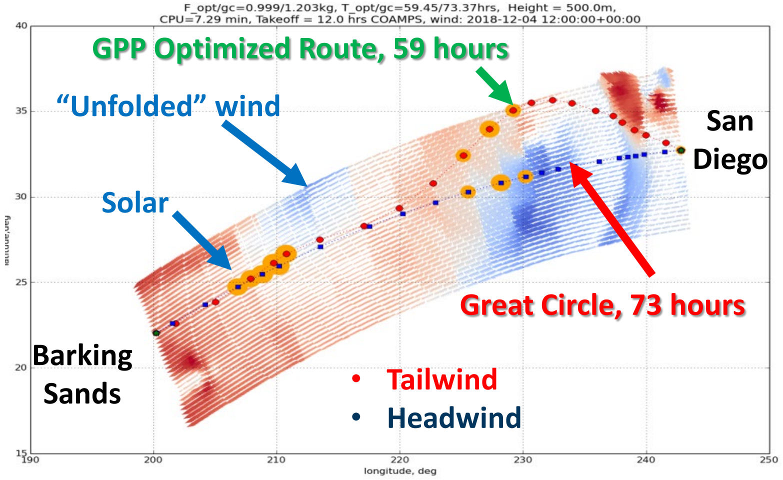
Advanced autonomy and CPU



Fuel Cell & H_2 Fuel Storage

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

Key Deliverable - previously not feasible routes can be optimally flown (5+ days) and recomputed onboard.



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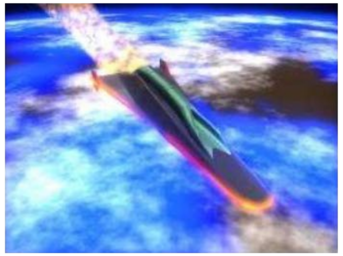
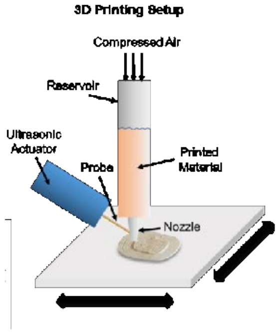
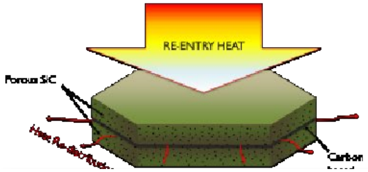
Additive Manufacturing of Metal Composites and Ceramics for Aerospace Applications







How

- We use the Vibration Assisted Printing (VAP) approach to process high solids-loaded mixtures for high-temperature ceramics and metals,
- For SiC-based ceramics, mixtures of crystalline powders and preceramic polymers are prepared, which produce dense net-shape ceramics upon sintering,
- Addition of graphite containing layers and channels improve thermal conductivity, which can diffuse out heat quickly from high temperature regions (leading edge, etc), keeping the maximum temperatures lower,
- Metal-loaded binder mixtures have uses in ramjets and hybrid rockets, combining high combustion heat of metals with high thermal conductivity, resulting in high specific impulse and thrust.

What

- Hypersonic vehicles require high temperature materials for thermal protection systems and propulsion components,
- These have been typically ceramics and graphite, which have advantages and disadvantages in thermal conductivity and oxidation resistance,
- Additive manufacturing (AM) can produce composite structures with precise control over the whole volume of the part at very fine scale to synergistically improve performance using strengths of different materials,
- Propulsion systems such as ramjets and hybrid rockets can benefit from a similar approach, improving energy density and burn rates,
- Current AM methods are limited in their ability to process particle loaded mixtures, required for net-shape parts with high conductivity and density.

Why

- Hypersonic vehicles can be operated at higher speeds due to higher temperature resistance and improved heat redistribution
- Improved ramjet and hybrid rocket performance translates to higher speed, range and energy density with a smaller form factor
- Hybrid motor capabilities can be enhanced through better structural strength and high regression rates, with net specific impulse approaching those of liquid rocket motors with lower cost and ease of operations.

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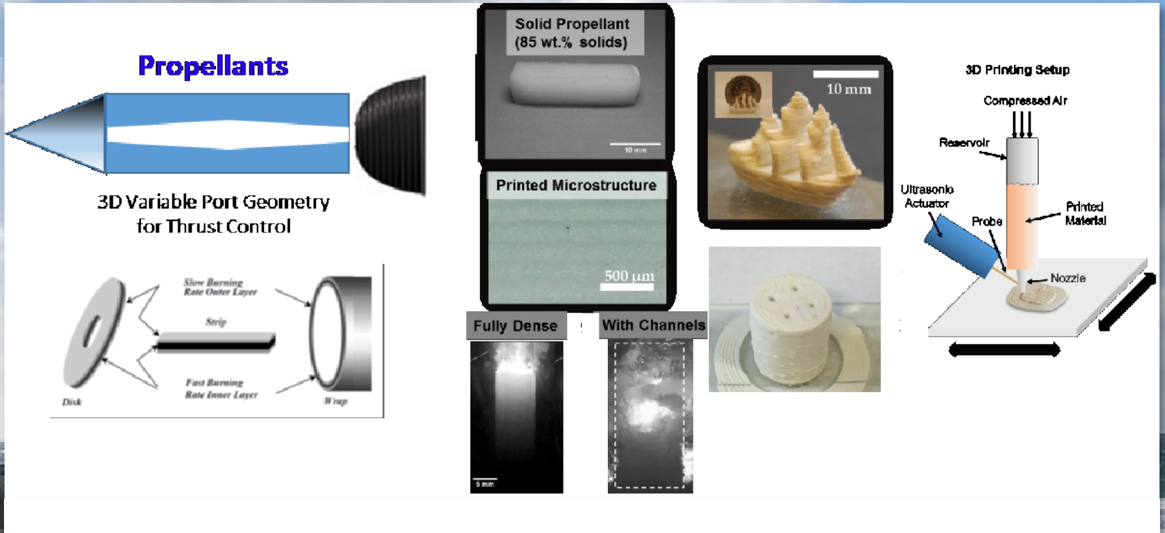
Additive Manufacturing of Propellants and Energetics



How

- We use a novel printing technology (Vibration Assisted Printing or VAP) that can process extremely viscous energetic precursors beyond state-of-the-art,
- The print nozzle is resonated in very specific ways to reduce friction that allows free flow of material at high speeds and resolution,
- Propellant precursors and polymer bonded explosives (PBX) with particle loadings beyond 80 vol% (90 wt.%) have been successfully printed at rates 100 mm/s at sub-mm resolution,
- Gun propellant analogues with no solvent addition can be extruded with the system.

What

- Solid propellants and energetic materials can benefit from additive manufacturing to improve their performance and safety,
- Gun propellant fabrication produces significant amount of waste and volatile organic compounds,
- Current AM methods are limited in their ability to process high particle loaded mixtures, required for high energy density, as well as suffer from low print speeds and resolution with viscous mixtures,
- We want to solve these issues with novel approaches in printing systems and materials formulations.

Why

- AM of propellants allows (i) tailoring of performance and (ii) optimum use of energetic ingredients for a given mission objective
- VAP AM can allow
  - Unique burn profiles and thrust history,
  - Reduce sensitivity of energetic mixtures,
  - Improve gun propellant ignitability at different temperatures while improving overall energy density through gradient porosity control,
  - Reduce waste and cost of propellant fabrication processes.

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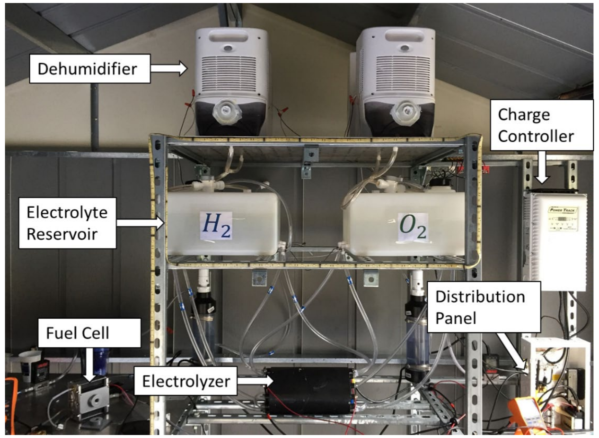
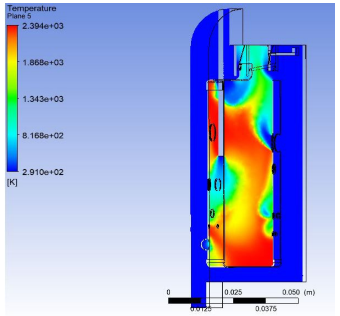
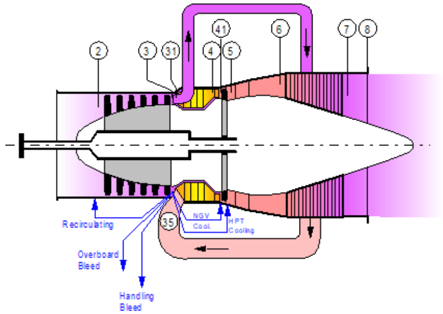
ESTEP - Self Contained Hydrogen to Electrical System



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.

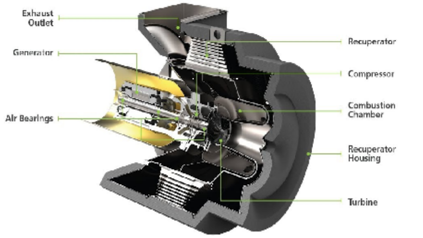




Objectives

- 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

30kW Capstone Microturbine Generator



Funding

- FY 19 $100k
- FY 20 $100k
- FY 21 $100k

Original vs Modified Capstone C30 Turbogenerator

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Advanced Casing Treatment for Transonic Compressor for Improved Operability

Objective/Description

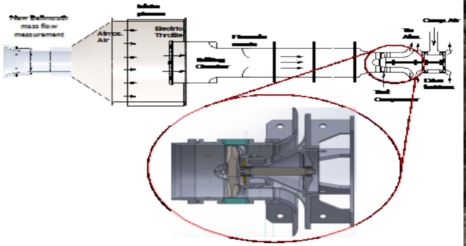
– Optimize compressor aero performance while also maintaining sufficient levels of stability margin throughout the operating range. To allow designers to continue to produce aggressive stage loading and improved stage stability characteristics without sacrificing performance.

Key Technologies

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

Schedule/Milestones

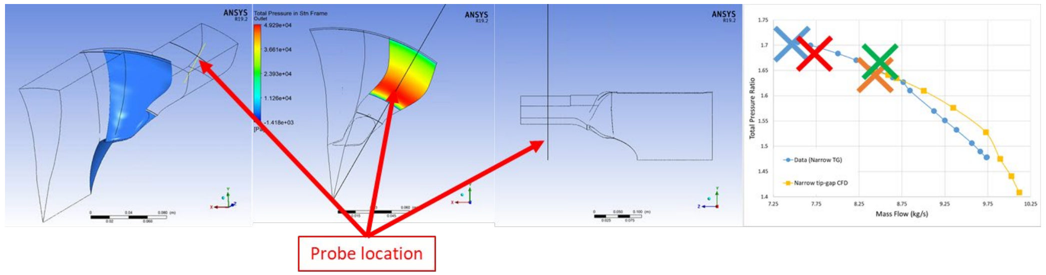
- Peer Review: 3/6/20
- POP: FY20 – FY 22
- Task 1: Baseline and circumferential grooves over a rotor configuration
- Task 2: Baseline and "S" grooves over a stage configuration
- Task 3: Targeted grooves over a stage and half (Inlet Guide Vanes) configuration.



Funding

– N00014-21-WX00891
– FY 20 $250k
– FY 21 $300k
– FY 22 $300k

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



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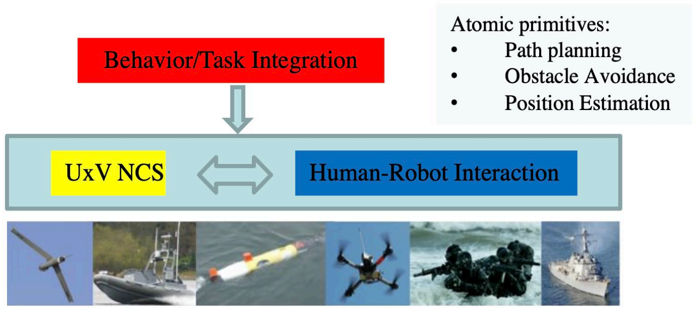
Accelerated Autonomy for UxV Networked Control Systems



- Hierarchy Protocol – manages vertical conflict resolution
- Priority Protocol – manages horizontal conflict resolution
- Behavior Tree manages execution

Methodology

- Research goal: Quickly integrate user-defined behaviors within the hierarchical UxV NCS software architecture.
- Approach:
  - Hierarchical architecture consists of AI/ML approaches for mid and upper layer decision-making
  - Design abstract behaviors software specification
  - Modify existing architecture for integration of multiple behaviors

Background

- UxV NCS is a combination of aerial, surface, ground and underwater vehicles connected via mesh networked comms
- The approach optimizes UxV positions with respect to parameters such as comms and sensor while simultaneously providing flexible control.
- Control flexibility permits a continuum of control authority from complete human control of each UxV to complete autonomy.

Operational Impact

- **Accelerate Autonomy in Unmanned Network Control Systems**
- The ability to rapidly integration horizontal and vertical behaviors offers the potential to rapidly increase autonomy in UxV NCS.
- While designed initially for expeditionary forces this applies to a wide set of DoD missions.
- Abstract behavior with UxV NCS specification permits permits independent behavior development.

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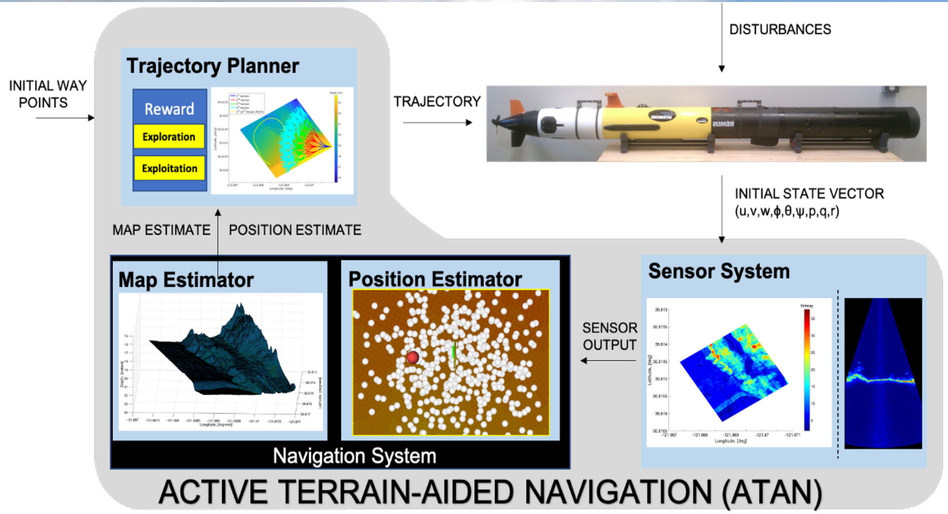
Active Terrain Aided Navigation



Methodology

- Active TAN – Use an information theoretical AI/ML approach for exploration and exploitation for dynamic path planning
- Balance exploration and exploitation:
  - Exploration – cover the mission area when the vehicle as confidence about its position.
  - Exploitation – Seek out and take advantage of terrain features when the vehicle is uncertain about its environment.

Problem

- GPS degraded or denied navigation solutions are required for current operational environments
- Traditional Terrain Aided Navigation (TAN) is limited due to a requirement for a prior bathymetric map.
- This is operationally limiting since frequently there is no prior bathymetry map.
- *Research goal*: Design an approach that permits accurate undersea navigation with no prior bathymetry map.

Operational Impact

- Research supports the Navy's NAVPLAN for unmanned systems autonomy.
- Minimize emphasis on GPS.
- No requirement for a prior bathymetric map increases operational effectiveness.
- Good for littoral environments.
- Not limited to undersea environments

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Aqua-Quad Hybrid Unmanned System
Prototype Development, Sensor Integration, and Field Experimentation

Aqua-Quad prototype flight-test on Dabob Bay with 1 kg tethered sensor

How

- The project is multi-disciplinary, involving groups from the MAE and Physics departments at NPS, as well as collaborators at NUWC Keyport.
- Mechanical and Aerospace:
  - Aerodynamic analysis of VTOL propulsion and energy-efficient mission planning
  - Large computational fluid dynamics simulations including propulsion modeling
  - Additive manufacturing for resilient, light-weight and water-tight parts
  - Full model CAD-to-prototype manufacturing
  - Advanced autopilot design
- Physics/Oceanography
  - Ultra-light implementation of vector sensors
  - Embedded data analysis for target detection and identification

What

- Aqua-Quad (Patents: 9,457,900 & 9,321,529) is a hybrid air/sea-vehicle essentially combining a quad-copter with a buoy, allowing for an air-mobile platform that can sense above and below the water surface. In support of USW, the prototype shown in the figure is carrying an acoustic sensor, hung below the copter on a long, thin tether. The copter is able to fly with the sensor hanging below as a slung load, and when the copter lands on the water, the sensor sinks to depth to carry out the mission.
- Short term goals include proof-of-concept demonstrations in collaboration with a team at NUWC Keyport, with planned participation in Trident Warrior and other high-visibility events.
- Long term goals include the integration of a solar recharge system and satellite communications to allow for multi-day persistence and beyond-line-of-sight operations. With the addition of ARSENL swarm autonomy and onboard data-processing, we hope to be able to demonstrate flocks of Aqua-Quads operating autonomously with collaborative behaviors to optimize acoustic target identification and tracking.
- The team is looking at several additional transition efforts for the existing and derivative designs.

Why

- There are numerous tasks, in all branches of the armed forces as well as the scientific community and private sectors, which require persistent, wide-area sensing in all operational environments – air, sea, and land. In 2014 CRUSER funded a concept that is a true hybrid platform, capable of use in all these environments, with both air and surface mobility, 24/7 sensing and long-reach communications - the Aqua-Quad.
- There are a wide range of missions where such a device could advance capabilities:
  - Undersea warfare: detecting and tracking surface and underwater targets
  - Littoral: detection of mines in shallow water and beach areas
  - Air-sea interface: sensing and communications bridging the air-sea interface
  - Marine-biology/preservation: tracking mammals
  - Climate: oceanographic and low-level meteorological sensing

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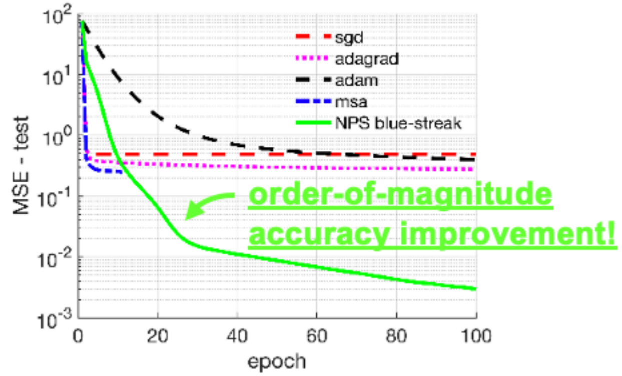
Naval Postgraduate School

Machine Learning Applications in Control and Optimization

Blue-Streak Learning Algorithm



NPS ' *Blue-Streak* is a parallelizable machine learning algorithm available to DoD for extreme accuracy and enhanced resilience to 'spoofing' inputs.

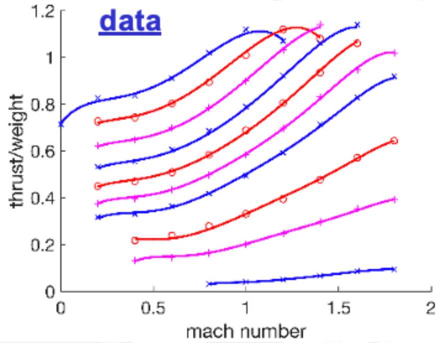
Contributing student:
LCDR Brendon Smeresky

AI-Based Hypersonic Design Optimization

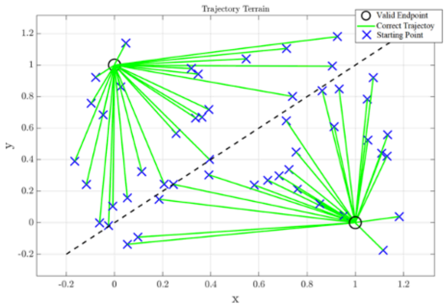
Artificial intelligence enhanced modeling of air vehicle systems performance can support design optimization of hypersonic vehicles, projectiles, rail-gun, etc.

Contributing student:
LT James Wickham

AI modeled performance curves using CFD/ empirical data

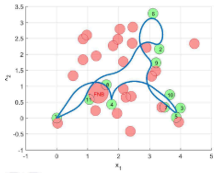


AI-Augmented Targeting System

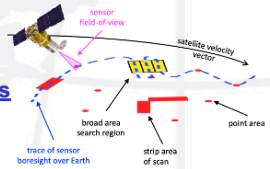


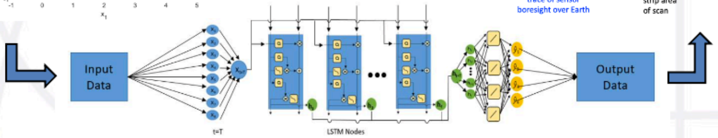
Merging artificial intelligence with nonlinear guidance algorithms provides concepts for supporting risk management and decision making for prioritizing future DoD weapons systems and/or sensor deployments.

Fast AI-Enabled Tasking/Collection



AI concepts can be used to enhance capabilities of DoD platforms and systems via software update.





Established AI concepts such as deep-learning, GANs, autoencoder etc. normally used for tasks such as image classification, automatic target recognition, have been repurposed to enhance the performance of various DoD platforms by a software change only.

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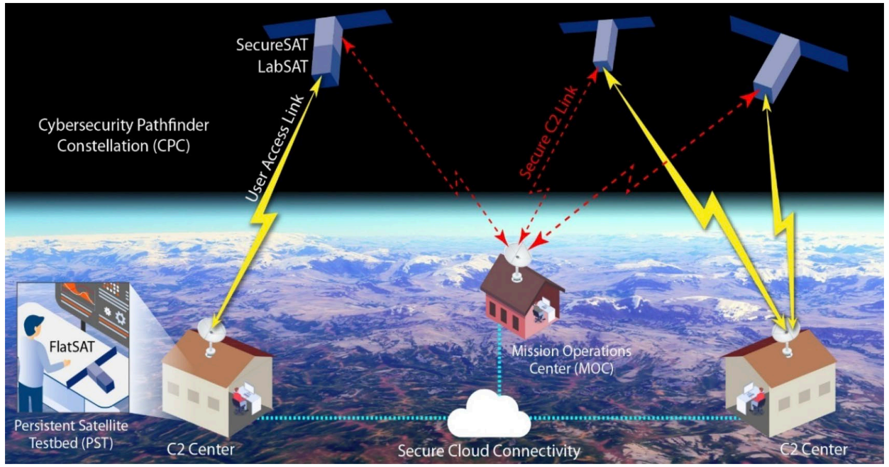
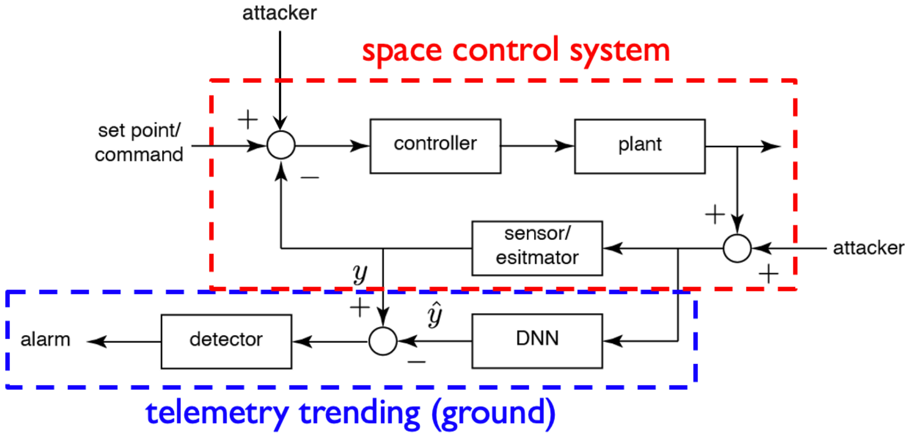
Security of ~~Cyber-Physical~~ Mechanical/Aerospace Engineering Systems

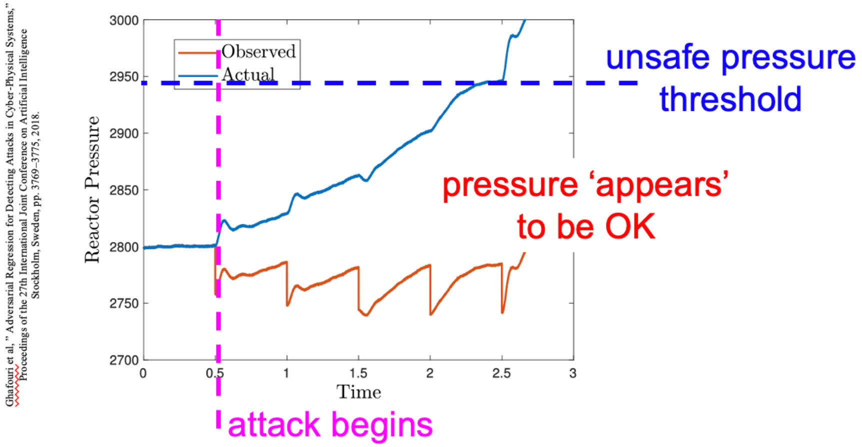
CRADA with Stephenson Stellar Corp



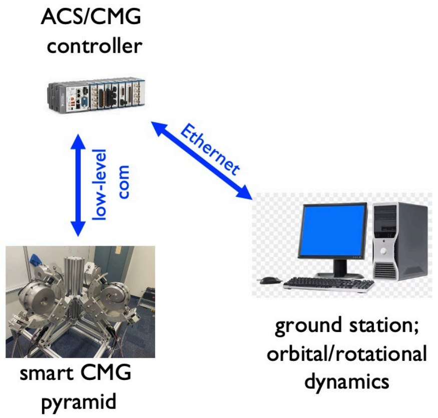
Attack Vector(s) for an Aerospace System



Example from a Chemical Process Plant



Laboratory Application to SSC System



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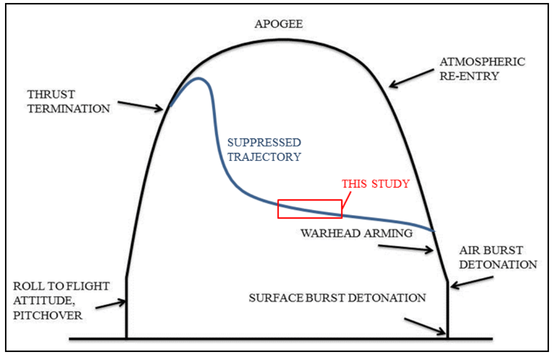
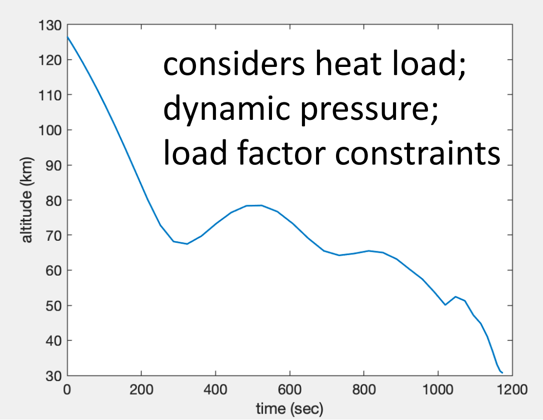
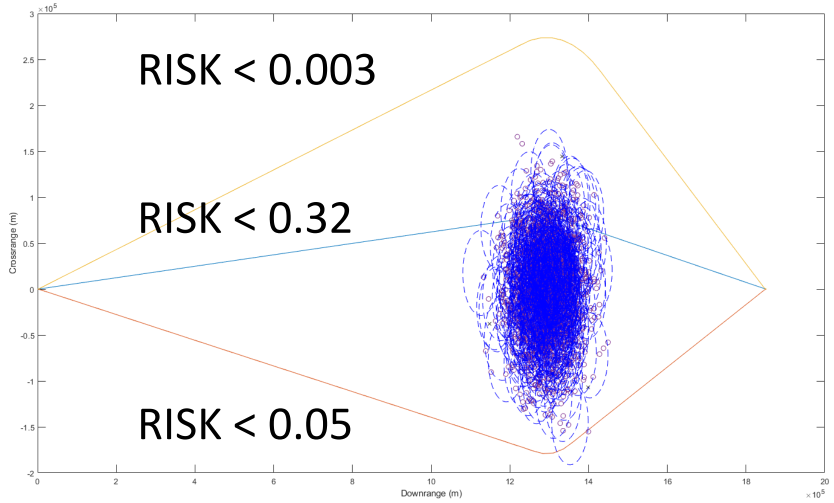
Addressing GPI Challenges – Hot off the Press

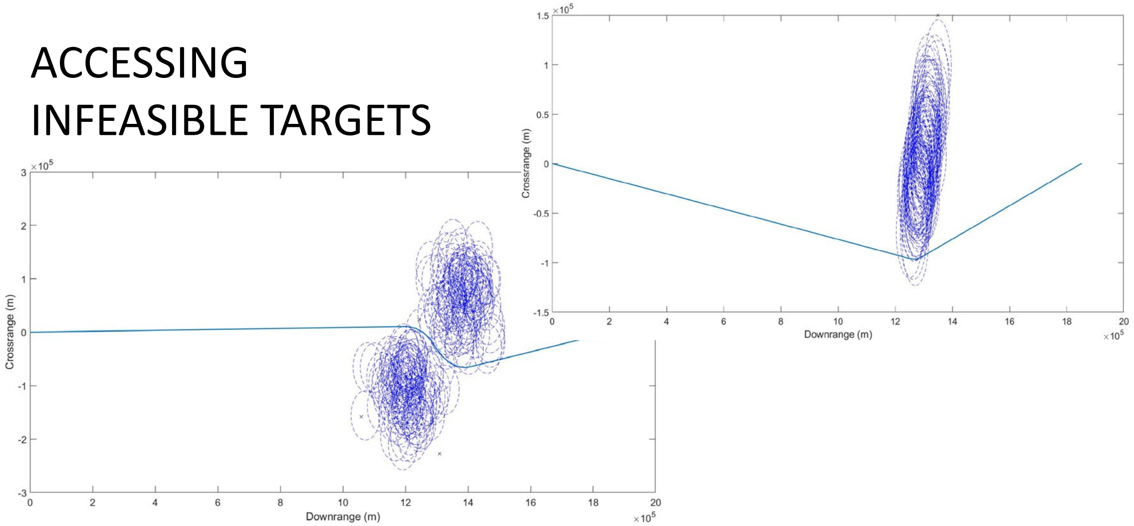
1. uncertainty management (guidance vs. control)
2. probabilistic optimization (LT Wickham's thesis - maximizing Pk; incorporating intelligence)
3. *integrated design optimization (trajectory drives requirements)
4. Available government IP: US10065312, US9849785, US9727034
5. LT Wickham's study sponsored by MDA







ACCESSING INFEASIBLE TARGETS



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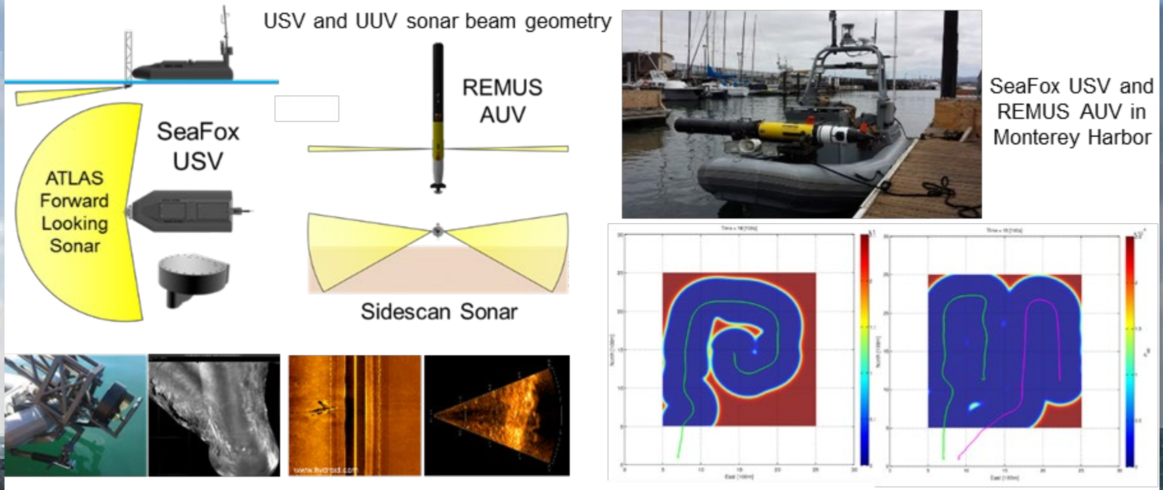
Optimal Mission Planning for Mine Countermeasures (MCM) Vehicles and Sensors



ATLAS FLS and image

Sidescan and FLS images

GenOC mission plans for single/multi-vehicle MCM

How

- Apply GenOC numerical solution framework for operationally relevant vehicles and sensors employed for mine countermeasures (MCM) missions.
- Develop physics-based models for different unmanned vehicles and MCM sonars.
- Solve optimal search problems to compute mine detection and identification trajectories.
- Apply *inverse* optimal search to identify optimal resource allocations for a given MCM scenario.
- Compare performance of optimal search trajectories against conventional lawnmower patterns.
- Identify optimal sensor or vehicle team configurations to reduce MCM mission timelines.

What

- Mine hunting is a challenging search problem due to wide variety of threats and environments.
- Heterogeneous UxVs and sensors bring new capabilities but pose new utilization questions.
- Generalized Optimal Control (GenOC) can compute vehicle trajectories that maximize sensor performance and minimize risk.

Why

- Under time and resource constraints, GenOC outperforms conventional search patterns.
- GenOC trajectories and performance benchmarks can improve mission planning and inform new MCM concepts of operation.

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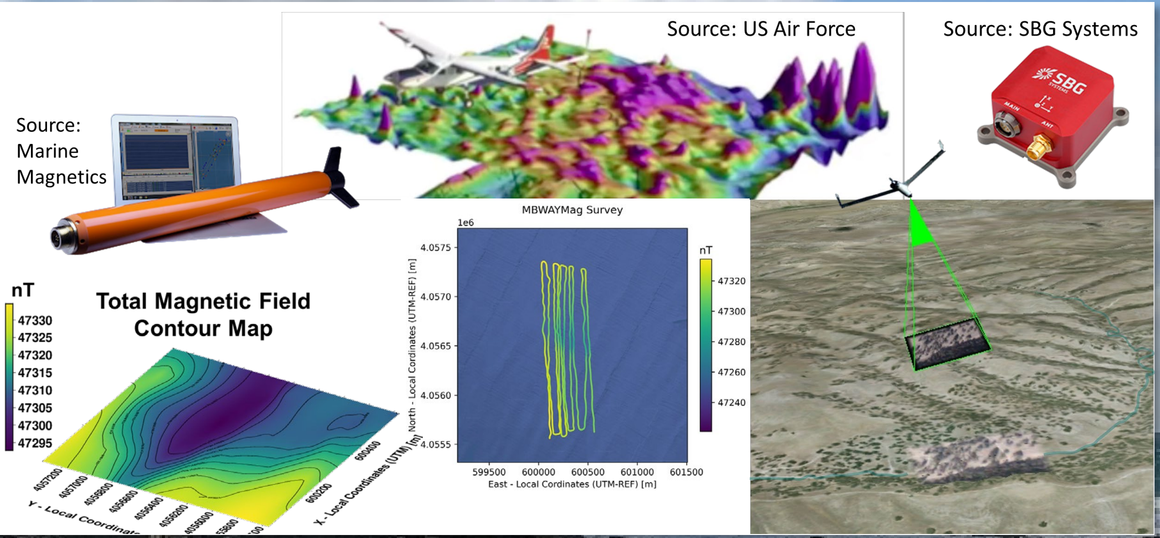
Non-Standard Navigational Methods for Unmanned Aerial Vehicles



How

- 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.

What

- 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.

Why

- ScanEagle Unmanned Aerial System (UAS) operations in GPS-denied areas
  - Group II UAS flown by Naval Special Warfare (NSW)
- Collaboration with other NSW-sponsored projects at NPS
- Naval Information Warfare Center-Pacific payloads for ScanEagle
  - SBG Systems Ellipse-N inertial measurement unit (IMU)
  - NVIDIA Jetson TX2 computer for NPS backseat driver interface

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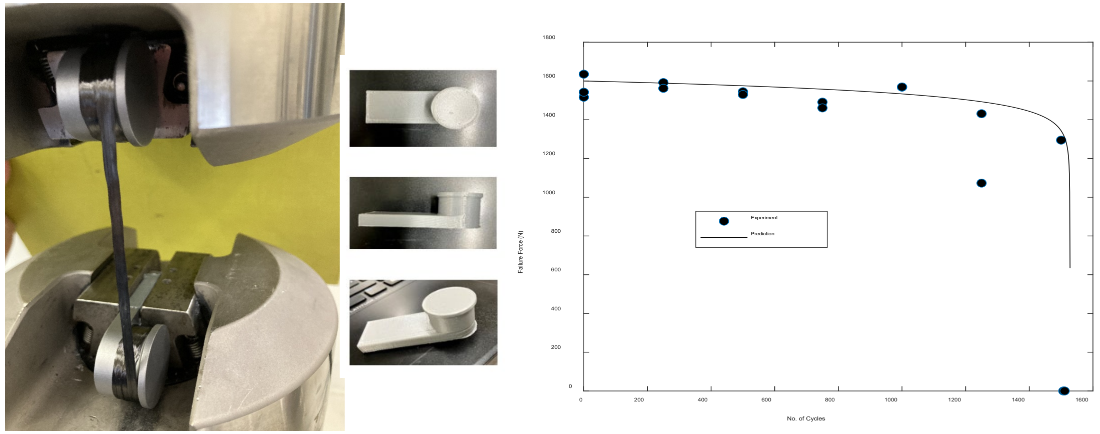
Fatigue Failure of Composite Materials and Structures

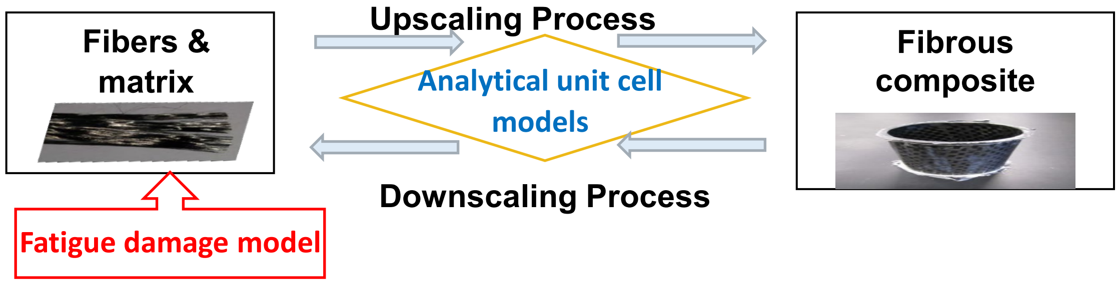
Young Kwon, MAE



Test of fiber bundle and cyclic test results

How

- Use of a Multiscale Approach linking the composite material behaviors to the constituent fiber and matrix material behaviors.



What

- 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.
- To build a library of material data for cyclic failure of constituent fibers.

Why

- 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.

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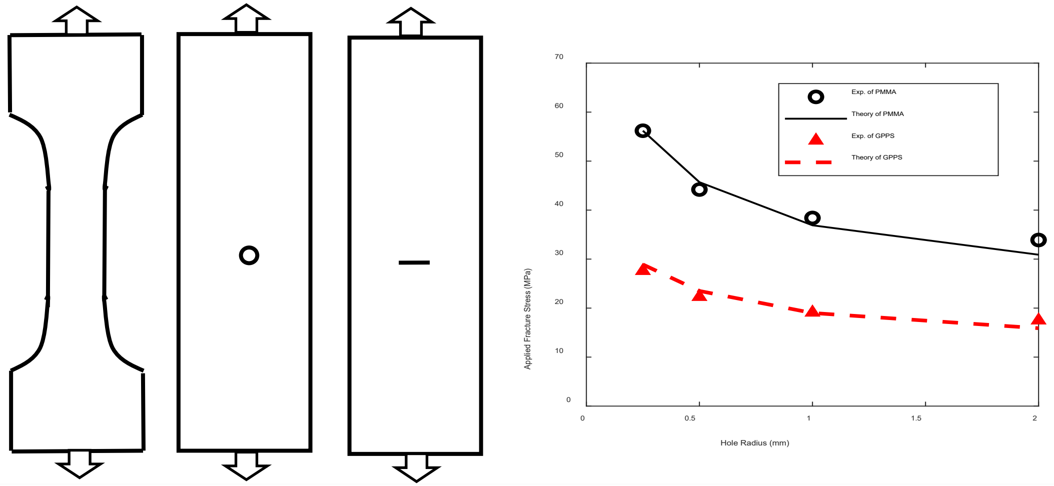
Development of Unified Failure Criteria
Young Kwon, MAE



Specimens with or without notches, and comparison of theoretical prediction to test data

How

- A set of failure criteria are developed. One is in terms of the maximum normal stress, and the other is in terms of the stress gradient.
- For uniaxial loading, the set of criteria are shown below:

$$\sigma_{\max} \geq \sigma_{fail} \qquad \left(\frac{\sigma^2}{2E}\right) \Big/ \left(\frac{1}{\sigma}\left|\frac{d\sigma}{ds}\right|\right) \geq \kappa_{fail}$$

What

- To develop a set of unified failure criteria for brittle materials regardless of the existence of notches and/ or their shapes for uniaxial loading.
- To apply the developed criteria for both isotropic and fibrous composite materials.
- To extend the criteria for multiaxial loading.

Why

- We do not have to select different failure criteria depending on whether there is a notch or what the shape of the notch is.
- We can predict the maximum applied load for any kind of notch in a part or component using a numerical analysis without extensive physical testing.

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Composite Structures Subjected to Underwater Shock Loading
Young Kwon, MAE


Underwater shock test and test setup in anechoic water tank

How

- Both experimental and numerical studies are conducted.
- Experiments are conducted inside an anechoic water tank.
- Underwater explosive loading is generated using either liquid nitrogen or the sudden burst of compressed air.
- A multiscale and multiphysics modeling and simulation is conducted.

What

- To understand and predict dynamic responses and failures of composite structures subjected to underwater explosion or implosion.
- To study the fluid-structure interaction of composite structures in water.

Why

- The study helps for design and analysis of more reliable and survivable sea platform structures made of composite materials against underwater shock loading.

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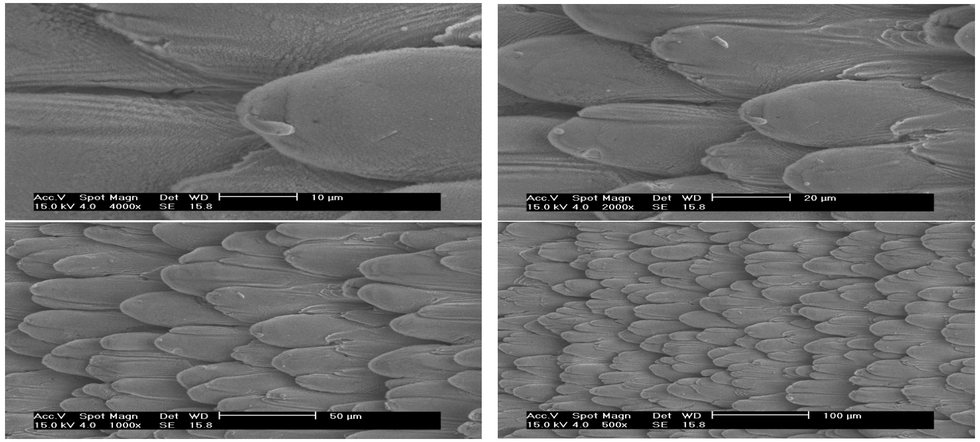
Frictional Drag Measurement for Superhydrophobic Surface

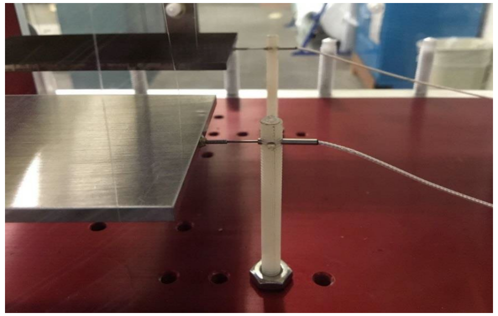
Young Kwon, MAE



Superhydrophobic surface created using a femtosecond laser

How

- Use of a unique water channel system designed and fabricated at NPS.



What

- To measure the reduction in hydrodynamic drag forces on superhydrophobic surfaces generated using the femto-second laser.
- Development of a water circulation channel which can measure the hydrodynamic drag force which is in the magnitude of milli-Newton.

Why

- There are numerous applications for superhydrophobic surfaces in the Navy.
- The research can provide qualitative and quantitative data for reduction in the frictional drag force.

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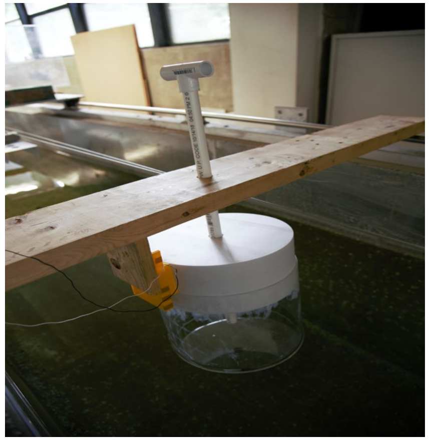
Triboelectric Generation
Young Kwon, MAE



Energy generation from wave motion

How

- Construction of a system with friction resulting from the environmental motion such as wave, wind, moving parts, etc.
- Consideration of both linear and rotational motions.
- Construction of prototype to demonstrate the energy generation concept.

What

- To generate electricity from frictional motion of two surfaces resulting from ocean wave or motions of ships and aircrafts, etc.
- To design and optimize the parameters to generate the maximum electricity from the frictional motion.
- Design and fabrication of triboelectric generation systems with applications to the Navy and DoD.

Why

- 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.

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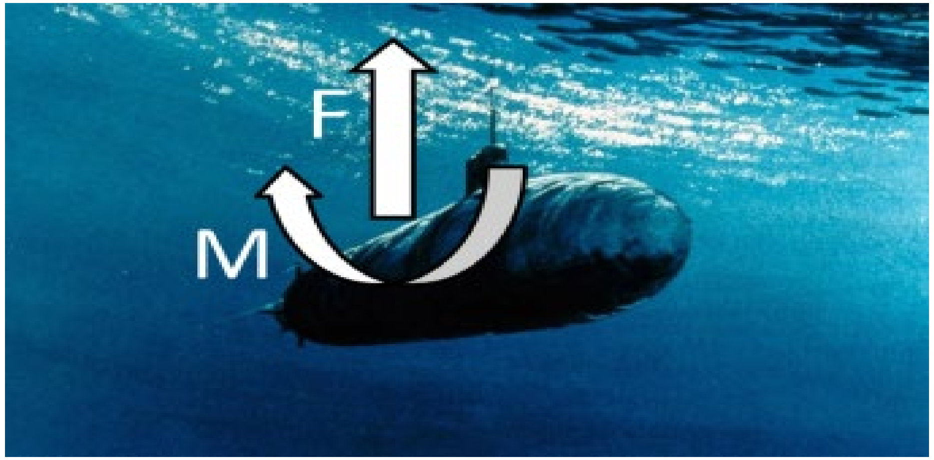
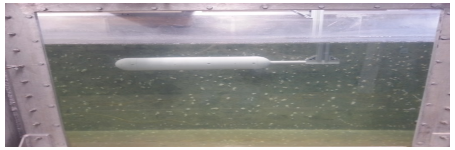
Navigation of UUV near Surface subjected to Sea Waves
Young Kwon, MAE

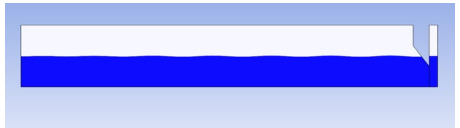


Wave loading

How

- Experimental study using a tow tank with wave maker.
- Numerical modeling and simulations using CFD.





What

- To study hydrodynamic loads on near surface UUV resulting from the sea waves to maintain the desired course of navigation.
- To apply the predicted hydrodynamic loading for the navigation control of the UUV motion.

Why

- Wave loading can alter the navigation path of the UUV and result in more energy consumption.
- Wave load can also breach the UUV by pushing it above the water surface.
- The predicted wave loads can provide information for an optimal navigation of the UUV during its mission.

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Composite Casing for Agent Defeat Penetrator
Young Kwon, MAE

Collaboration between NPS and LLNL, and test setup for composite casing containing explosive material

How

- Physical testing with high energy explosives.
- Use of Photon Doppler velocimetry (PDV) and high-speed cameras to measure and view the deformation of composite cylinders and their failure.
- Computational modeling & simulations using a multiscale and multiphysics approach.

What

- To design and fabrication of composite casing for agent defat weapons.
- To understand and predict dynamic failure of composite materials and structure under very high strain rates.
- To develop material failure modeling in terms of constituent materials.

Why

- The developed weapon can neutralize bio- and chemical-weapons which are stored in a bunker.
- This is a counter-mass destruction weapon.

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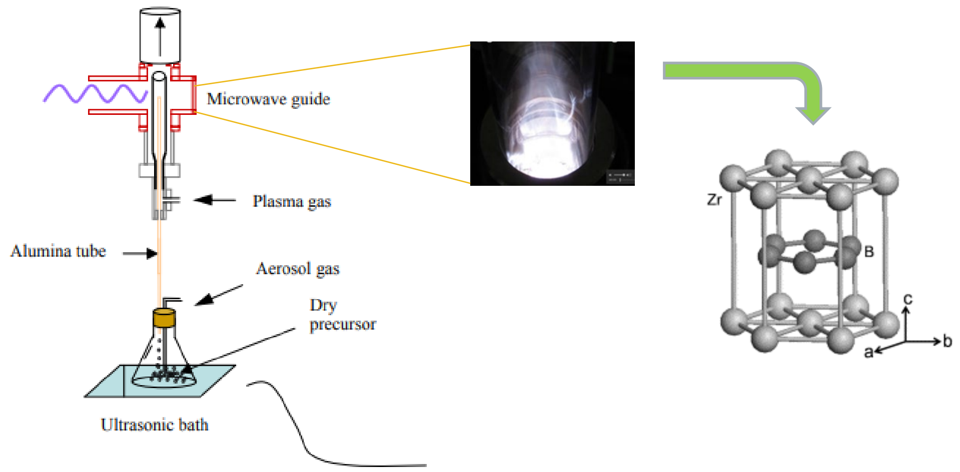
Dr. John Molitoris

Ultrahigh Temperature Materials for Hypersonic Systems Readiness

Naval Postgraduate School



Atmospheric microwave plasma torch system to produce ultrahigh temperature materials

How

The approach to fabricate the UHTC will employ a low power atmospheric microwave plasma system operating under atmospheric conditions to generate a combination of borides and carbides known for their thermal resistance. The formulations employed will be selected from UHTC known to be more resistant to oxidation.

The UHTC particulates generated will be integrated into a layered structure containing a graphitic or SiC base. The composite samples produced will be analyzed by X-ray diffraction, electron microscopy, energy dispersive spectroscopy to determine crystalline structure, microstructural features, and composition.

Thermogravimetric and differential scanning calorimeter analyses will be employed to study the oxidation resistance of the new composites up to 1400^{o}C.

The ablation resistance will be tested by exposing the materials to temperatures of about 2000 ^{o}C achieved by an oxyacetylene flame and evaluating its effects.

What

This project aims to develop materials that have potential to withstand the high temperatures encountered by systems used in hypersonic flight. Multilayered architectures that combine the high melting temperatures and oxidation resistance of ultrahigh temperature ceramics (UHTC) (top) and graphitic composites and/or silicon carbide (bottom) are proposed along with the technical assessment of their performance.

Why

- Ceramic tiles have traditionally been used for aircraft thermal protection; however, their brittleness and low damage resistance and high cost have limited their application.
- Metallic thermal protection structures, super alloys, and intermetallic compounds have also been considered, however, their melting temperatures and susceptibility to oxidation are a drawback.
- Therefore, the search for ultrahigh temperature resistant materials is still a pressing need for DoD and a fertile area of research.

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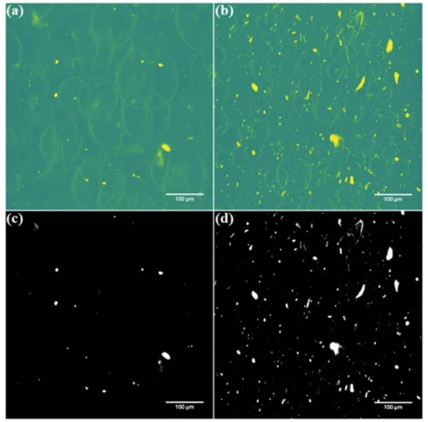
Introduction of Rare-Earth Oxide Nanoparticles in CNT-Based Nanocomposites for Improved Detection of Underlying CNT Network



Micro-CT tomograms in high-contrast color revealing CNT network and pores and greyscale depicting only the CNT network: (**a**,**c**) untreated CNT nanocomposite; (**b**,**d**) Eu:Y_2O_3-CNT nanocomposite.

How

Rare-earth oxide nanoparticles (Eu:Y_2O_3) are synthesized on CNT walls using wet impregnation techniques. The adherence of the synthesized nanoparticles to the CNT walls is documented via transmission electron microscopy.

The crystalline phases generated during the various fabrication steps are determined using X-ray diffraction. Deep ultraviolet-induced fluorescence of the Eu:Y_2O_3-CNT nanostructures is verified.

The impacts to nanocomposite electrical properties resulting from dopant introduction are characterized.

The scanning electron microscopy imaging of CNT pulp and nanocomposites fabricated from untreated CNTs and Eu:Y_2O_3-CNTs are compared, resulting in improved contrast and detection of CNT bundles. The micro-CT scans of composites with similar results are achieved.

What

- Analytical methods for validating carbon nanotube (CNT) nanofiller dispersion, and for assuring that the properties they induce extend to the entire volume are destructive and inhibited by poor resolution between matrix and tube bundles.
- Herein, rare-earth oxide nanoparticles are synthesized on CNT walls for the purpose of increasing the contrast between their network and the surrounding matrix when studied by imaging techniques, alleviating these issues.

Why

Nanoscale composites utilizing carbon nanotube (CNT) filler allow for significant reductions in resistivity of an otherwise highly insulating matrix material while requiring extremely low CNT loadings. These improved conductivities result in an attractive material with extensive applications in diverse industries, but particularly for electrostatic discharge (ESD) and electromagnetic interference (EMI) prevention. These enhancements are heavily dependent on nanofiller dispersion in the matrix material. Thus, dispersion control becomes essential to ensuring uniform properties throughout the composite and eliminating hotspots that could affect reliability or performance.

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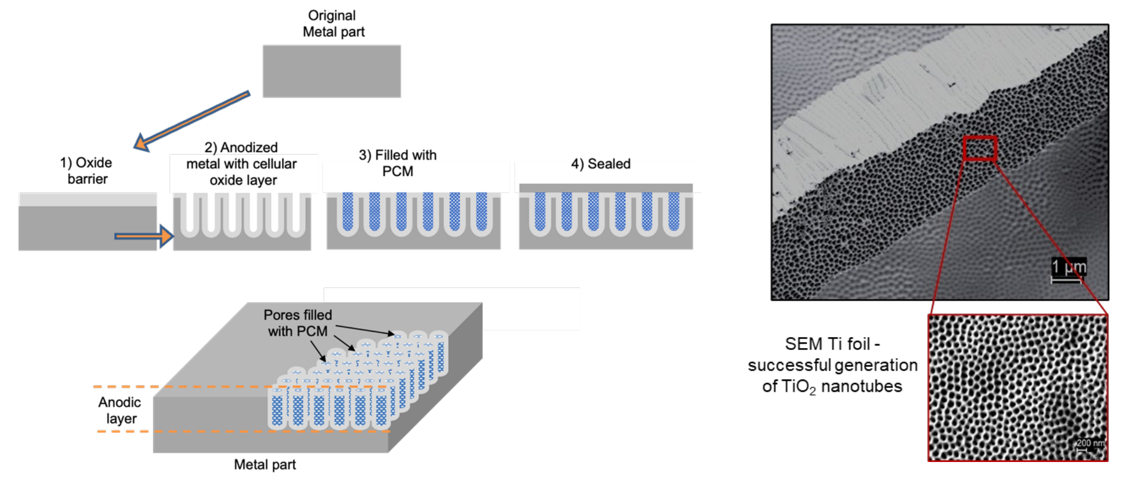
Thermal Management through Functional Material Design



Exemplary strategy for PCM integration at the microstructural scale

How

This project aims to integrate phase change materials directly in the skin/surface of the materials, as a thermal management strategy with potential to mitigate the detrimental effects of elevated temperatures without interfering with the basic function of the components.

Some of the desired features in the resulting system include to

a) place the PCM in close contact with the base material while being chemically isolated from it,

b) allow the PCM integration into components with complex and irregular shapes,

c) use formulations that present transitions at moderate to high temperatures, and

d) modify only the surface of the material, leaving the base properties unaffected.

What

- Despite the proven effectiveness of using Phase Change Materials (PCM) as a passive way to absorb or release heat, their integration into existing metallic systems has proven difficult.
- When the PCM employed relies on a phase transformation from liquid to solid (and vice versa), a reservoir is needed to isolate them from the rest of the components, prevent leaks and extend their cycle life.
- This project aims to identify strategies for PCM integration into specific metal /alloy host systems at the microstructural scale. The project objectives include identifying material formulations, methods to produce the material in the desired shape, size, or envelope, to testing thermal properties and compare benefits associated with the PCM introduction. The project also seeks to develop key partnerships that could facilitate the technology transition/adoption.

Why

The energy consumption associated with managing thermal loads in diverse environments is significant, and has a direct correlation with systems' performance, reliability and operational costs. Finding new strategies that use phase change materials to manage extreme environments is expected to improve the material/component/system performance and extend its useful life.

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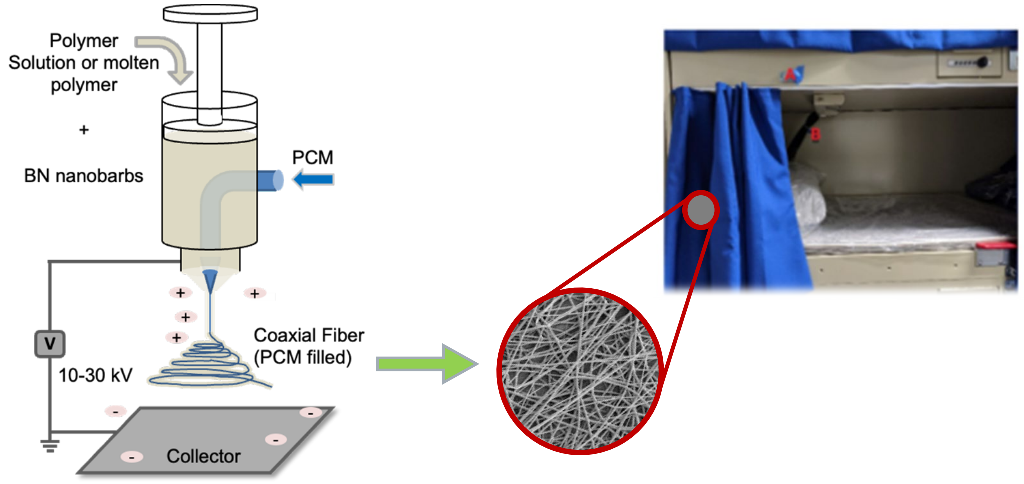
Phase Change Materials Integration into Fabrics



Electrospinning system employed to produce coaxial fibers that include a PCM filler and potential application

How

- Identified electrospinning synthesis, as the most viable approach to integrate phase change materials into fabrics/fibers.
- Statistical analysis of the material combinations published to date has rendered some insights regarding the most promising formulations and their targeted transition temperatures.
- Experimental approach will provide proof of concept of materials that fulfill fire retardant and safety regulations while being able to serve to reduce temperature loads in living and storage spaces.

What

This project seeks to include phase change materials into fabrics, to generate materials capable absorb or release heat to help regulate the temperature of living and storage spaces.

Why

The energy consumption associated with managing thermal loads in diverse environments is significant, and has a direct correlation with systems' performance, reliability and operational costs. Finding new strategies that use phase change materials to manage extreme environments is expected to improve the material/component/system performance.

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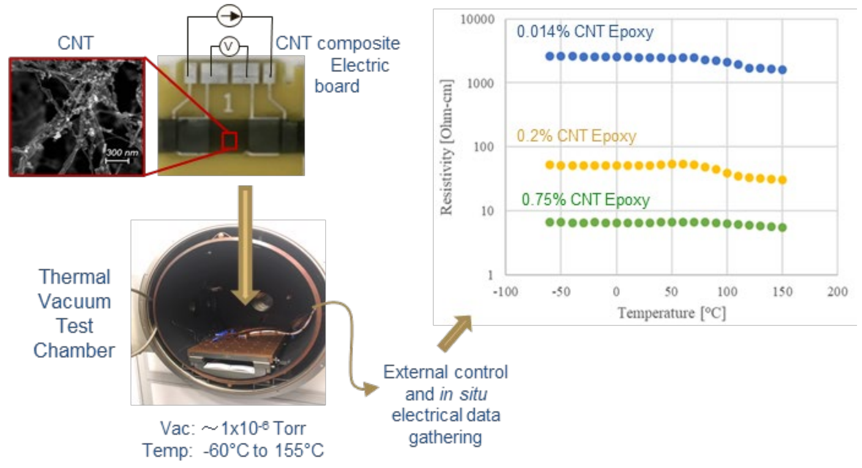
CNT Composite Testing in Simulated Space Environments

Naval Postgraduate School



Epoxy – Carbon nanotube composite testing under simulated space environments

How

In this study, the electrical properties of CNT epoxy composites containing low CNT loadings (less than 1%) were measured *in-situ* while the specimens were exposed to diverse simulated space conditions.

A thermal vacuum chamber was employed to produce the low pressures and temperatures associated with low earth orbit.

A solar simulator was used to replicate solar irradiance.

A convection oven was used to determine the effects that could only be attributed to temperature variations.

The changes in resistivity exhibited by the composite specimens are reported for each scenario along possible mechanisms that could explain the observed behavior.

What

The objective of this project was to determine the electrical properties of carbon nanotube (CNT) composites containing low loadings of nanotubes (<1%) using environments that resemble space conditions such as low temperature and pressure.

Why

The properties of CNT composites are known to suffer changes when exposed to space conditions or simulated space environments. A more in-depth understanding of the magnitude of those changes could help improve the design of systems that contain them, produce more accurate predictions of their performance, or even open the possibility of new applications.

Mechanical and Aerospace Engineering Department

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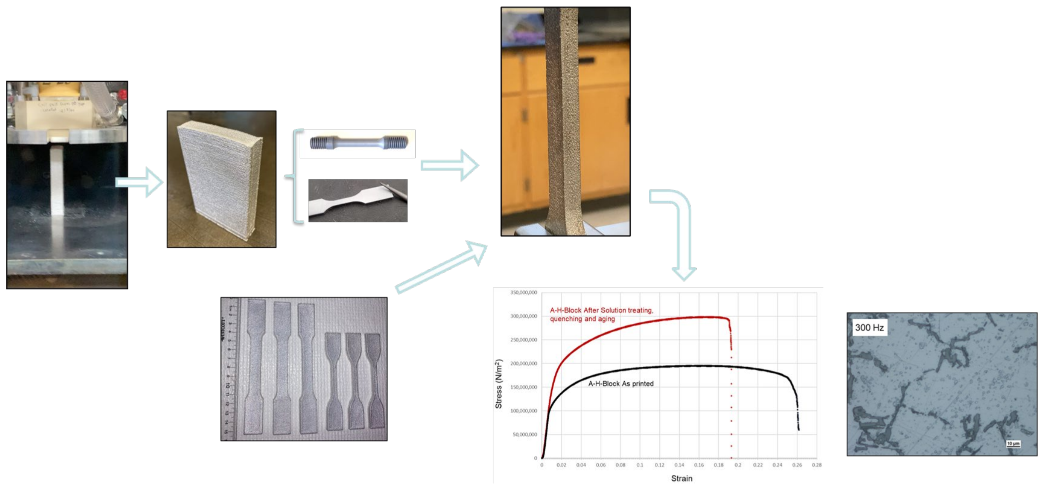
Naval Postgraduate School

Mechanical Properties of Aluminum Alloys (A356) Produced by Liquid Metal Printing



Workflow of the mechanical and microstructural characterization of aluminum 3D printed alloys

How

- Conducting tensile test of specimens as printed and after solution treatments and aging steps.
- Identifying the microstructural features responsible for the observed yield and tensile strengths, % of elongation and hardness.
- Identifying the presence or absence of pores, inclusions, or defects that could cause early failures.
- Documenting the material performance and comparing it with alloys of similar composition produced by traditional routes such as casting.

What

- This project is part of a larger effort that seeks to use liquid metal printing strategies to additively manufacture aluminum alloys.
- Our team has undertaken the mechanical and microstructural characterization of 3D printed parts and those of specimens that have been printed, solution treated and aged, in order to compare their performance with the benchmarks established by military standards of similar alloys.

Why

- One of the main advantages of AM over other approaches to fabricate materials is that parts are assembled using only the amount of material that the new piece will be composed of, there is no need to cut away sections from a larger piece. In contrast, customary methods start with a large body of material that through cutting, milling, drilling or etching, gets reduced in size.
- Parts created through AM require no further assembly and, since there is no waste of material, are expected to reduce costs.
- In the context of naval applications, AM techniques are expected to reduce the turn-around times required to resupply the fleet when components fail or reach end of life.

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Student: LT William Kimberl

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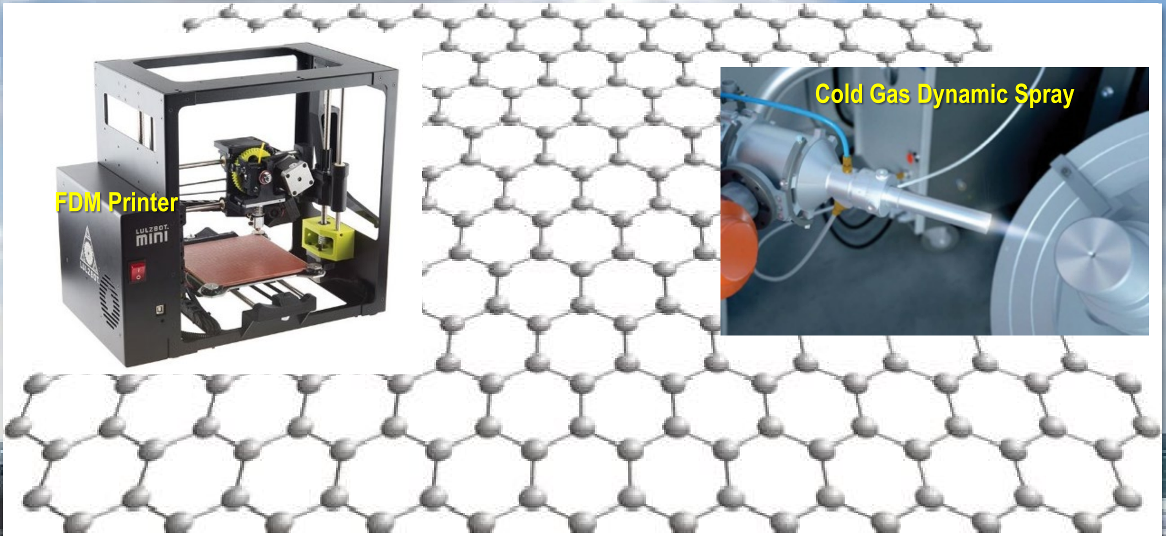
School

Using Additive Processing to Harness and Implement Graphene Technology for Wear and Corrosion Protection



How

- Graphene nanoplatelets (GNP) will be incorporated into PETG polymer by cryomilling the materials together and extruding fibers suitable for 3D printing.
- High energy ball milling (HEBM) will be used to mix GNPs with cold spray grade aluminum powder
- PETG-GNP composite polymer will be printed using a Lulzbot FDM 3D printer
- Al-GNP composite coatings will be deposited onto Al6061 substrate using cold spray
- Dry sliding wear tests of PETG-GNP and Al-GNP materials will be conducted
- Salt fog and accelerated weathering tests will be conducted on PETG-GNP and Al-GNP

What

- Graphene was isolated in 2004 in an effort that resulted in the award of the Nobel Prize in Physics
- In the ensuing decade and a half graphene has been studied extensively for its extraordinary properties and the ability to confer those properties onto other materials
- The time is ripe to attempt to harness this exciting material and implement it in new technologies that can deliver anti-corrosion and anti-wear solutions to the Navy
- AM has emerged as a promising way of conducting advanced manufacturing at the site of need
- Fused deposition modeling (FDM) and cold spraying will be utilized in this study to incorporate graphene into conventional naval materials to enhanced wear and corrosion resistance

Impact and Research Questions

- Additive processing techniques combined with new material solutions such as graphene could provide a combination of high performance and cost savings that enable rapid technology transition.
- The goal of this effort is to provide analysis and quantifiable data to identify applications where graphene can be incorporated into naval uses by providing enhanced performance at a cost benefit
- Of specific interest to N9 Destroyers Branch Head is whether graphene can be used in protective coatings for ship hulls, fuel tanks, or other parts exposed to severe wear and corrosion
- This study will evaluate if FDM 3D printing or cold spraying can create graphene infused parts
- Systematic tests will determine if graphene infused coatings or parts provide enhanced wear resistance

Mechanical and Aerospace Engineering Department

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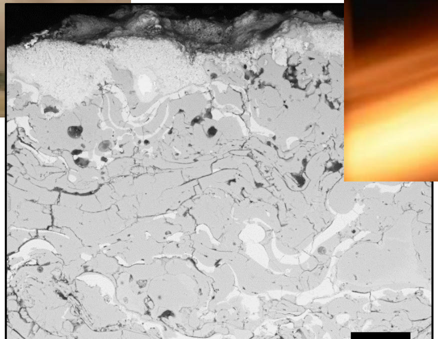
Sandphobic Thermal/Environmental Barrier Coatings for Gas Turbine Engines

SERDP
DOD ▪ EPA ▪ DOE

17 MAY 2015 – Brownout conditions over Hawaii result in V22 crash + loss of life (DoD image)



Patented Sandphobic Coating

Burner Rig for Testing Coatings

How

Pt Crucibles

What

- Collaborative team to <u>**develop sandphobic T/EBCs for GTEs**</u>
  - NPS (government/academia)
  - ARL (DoD Lab)
  - Oerlikon Metco (Industry)
  - Stony Brook University (academia)
- NPS Tasks:
  - Characterization of burner rig and engine tested sandphobic coatings
  - CMAS kinetics on novel material systems
    - Currently investigating ultra high temperature ceramics and high entropy borides

DEVCOM ARMY RESEARCH LABORATORY

oerlikon metco

Stony Brook University

Impact

- Gas turbine engines operate at high temperatures to achieve high efficiency
- Sand and other environmental particulates (ash, salt, debris) are ingested into engines
- Ingested particulates melt and adhere to ceramic coatings that protect the engine
- Acute damage can consist of clogging of air channels and rapid engine failure
- Long-term degradation from chemical reactions between sand and coatings degrade protection
- Sandphobic coatings would enable military aircraft to operate in brown-out conditions, polluted megacities, and urban canyons

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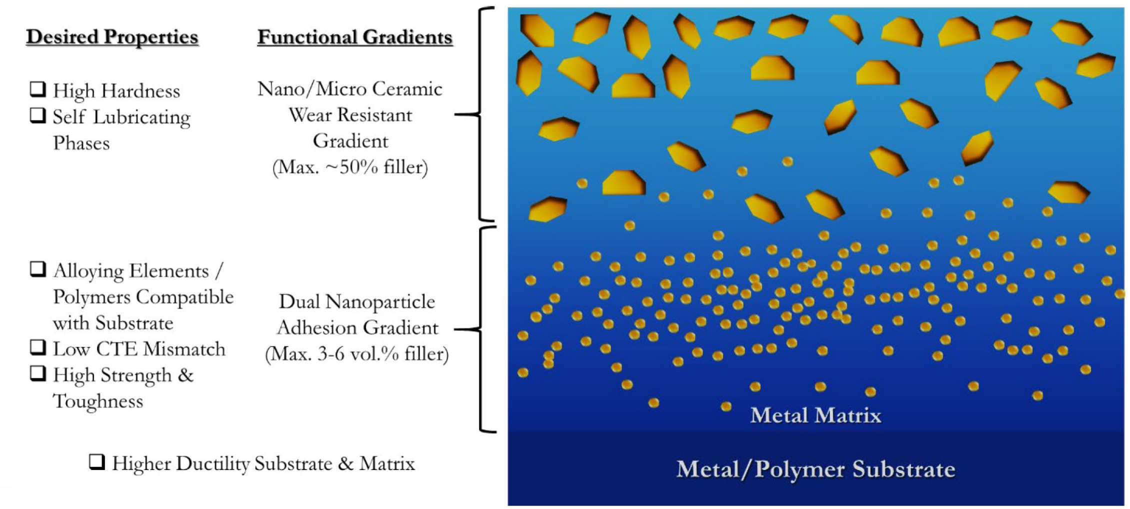
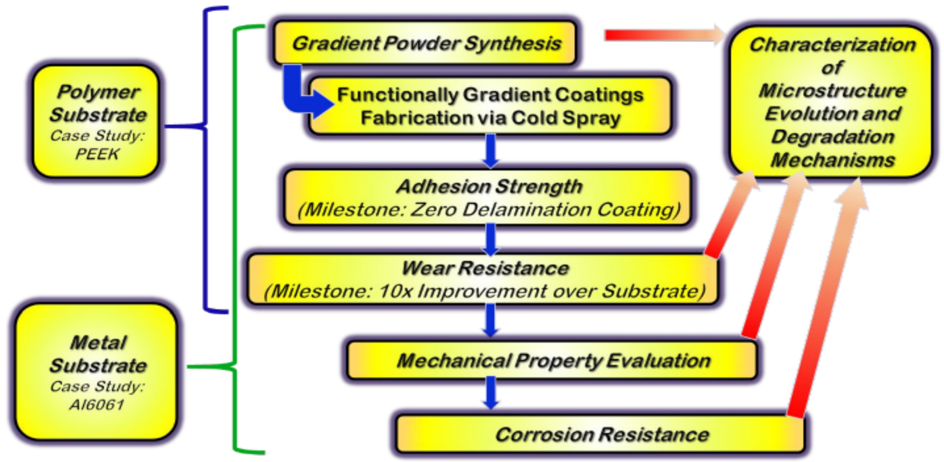
Functionally Graded Cold Sprayed Hybrid Coatings for Multi-Material Structural Repair and Wear Protection



How



What

Background:

- Aerospace materials are the underlying enabling technology for air vehicles and weapons.
- Leveraging recently discovered multi-functional materials (graphene, carbon nanotubes) in aerospace structures has the potential of enhancing performance while reducing parasitic weight.
- Cold spray technology is being implemented in navy shipyards to repair structures and could potentially replace welding in many applications.

Objectives:

- To design and fabricate cold sprayed coatings with zero delamination at substrate/coating interface.
- Develop damage-tolerant coatings that drastically enhance wear resistance and life.
- Utilize 1D and 2D nanomaterials to endow tailored functionality across the thickness of a cold sprayed coating.

Why

- New technique for protecting and repairing metallic and polymeric materials.
- Develop ***cold spray*** as a technique to protect and repair lightweight aerospace structures.
- Functionally graded and integrated coatings could enable more widespread utilization of light metals such as magnesium and aluminum.
- Wear resistance coatings could find applications in bearing, cutting and drilling tools, and brake discs.
- Approach could be tailorable to applications requiring corrosion resistance or electrical conductivity.
- Successful development of ***cold sprayed functionally graded materials could be quickly transitioned*** due to the inherent portability and scalability of cold spray.

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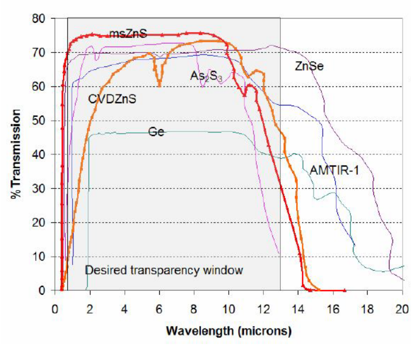
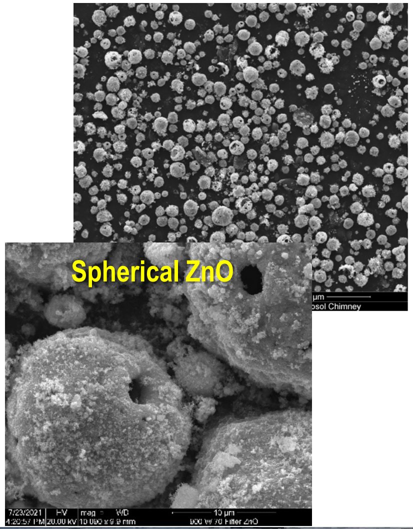
Synthesis and Characterization of Sulfide Particulates for Transparent Ceramic Applications

DEVCOM ARMY RESEARCH LABORATORY

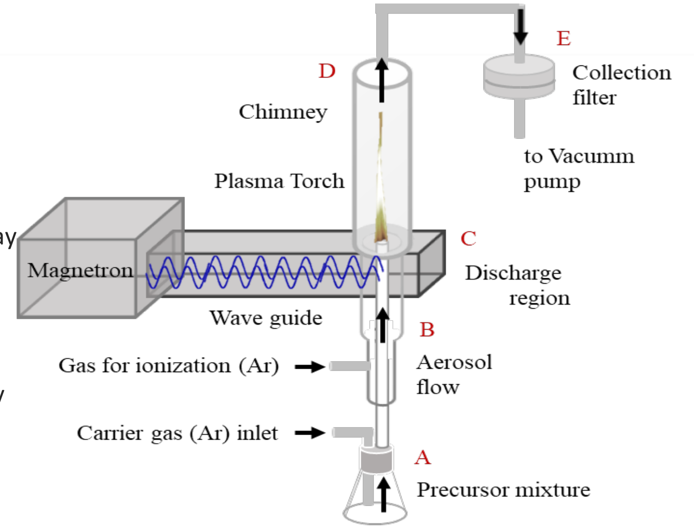




Plasma Torch to Synthesize Spherical Ceramic Particulates

How

- Spherical Zinc Oxide (ZnO) has been produced using the Aerosol through Plasma (ATP) technique
- Sulfurization experiments are underway to sulfurize the spherical ZnO into zinc sulfide (ZnS)
- Characterization of sulfide morphology using SEM and TEM
- Phase characterization using XRD



What

- **Low wave infrared (LWIR) ceramics** are needed to enable guidance of hypersonic projectiles in a GPS-denied environment
- *Current optical windows cannot transmit LWIR*
- Current materials available for LWIR transmittance may not be sufficiently durable
- There is a need to fabricate dense sulfide ceramics and **current feedstock materials are not suitable**
- **Spherical, nanometric, and phase-pure sulfides** must be synthesized to enable transparent ceramics

Why

- Spherical and nanometric sulfide particulates are ideally suited for sintering dense ceramics
- Dense ceramics provide durability and optical transmittance
- Plasma synthesis of sulfide particulates would provide a route to attain suitable feedstock powders
- Successful synthesis of zinc sulfide would demonstrate viability of ATP and could be used to synthesis emerging LWIR materials such as Calcium Lanthanum Sulfide (CLS)
- Plasma technique is scalable (used in industry) to produce large quantities of material

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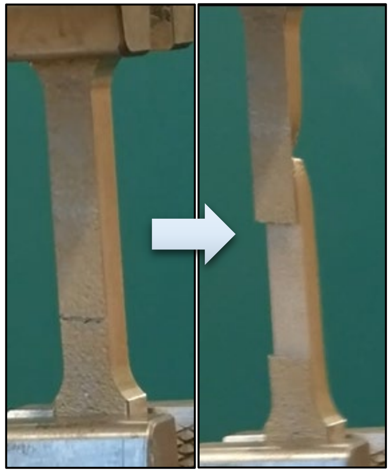
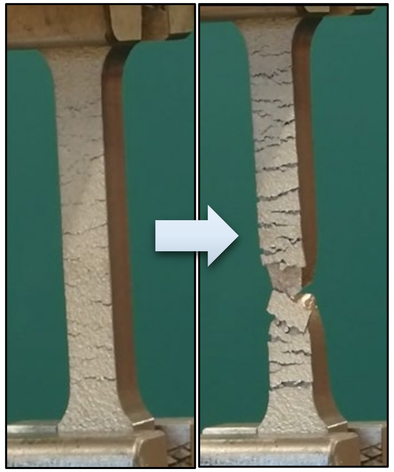
Naval Postgraduate School

Effects of Cold Spray Repairs on the Mechanical Properties of a Component

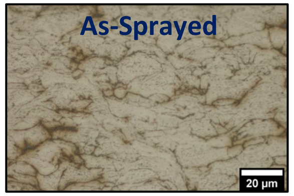


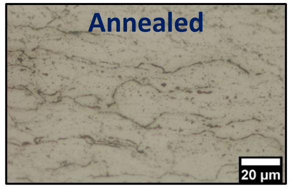
As-sprayed



Annealed

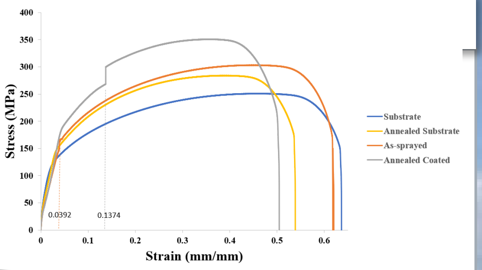
Coating Microstructures

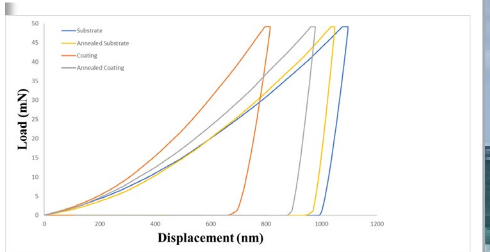




How

- Commercial Cu-Ni powders were cold sprayed in-house
- Cold spray parameters were optimized using nitrogen to deposit a thick (10% of substrate) coating
- Heat treatments are conducted in-house at 650 C
- Mechanical properties are evaluated using:
  - Adhesion strength pull tests
  - Tensile testing of coated coupons
  - Nanoindentation





What

- Cold spray is an emergent additive deposition technique for metals that has matured to the point of being implemented in Navy shipyards
- Copper nickel (Cu-Ni) is a widely used alloy with good strength and corrosion system used in pipes, heat exchangers, and other components needing good thermal conductivity
- Cold spraying of cupro-nickel alloys is hardly studied in the literature
- There is a need to understand the effect of cold spray deposits on the overall mechanical behavior
- Few studies investigate the mechanical behavior of thick cold sprayed coated specimens, most studies look at thin coatings or stand-alone coatings

Why

- The Pearl Harbor Naval Shipyard and Intermediate Maintenance Facility (PHNSY & INF) recently acquired a cold spray system to be utilized for repairs
- It is envisioned to use cold spray to repair corroded or worn Cu-Ni components
- The use of annealing can greatly enhance mechanical performance of cold spray deposits:
  - ***Adhesion strength is higher than that of high strength adhesive***
  - Annealing reduces porosity and enhances **both** ductility and strength
- Cold spray partially cold worked substrate and had sufficient ductility **to bear loads and remained on substrate past the point of substrate yielding** *(the typical design criteria for failure)*

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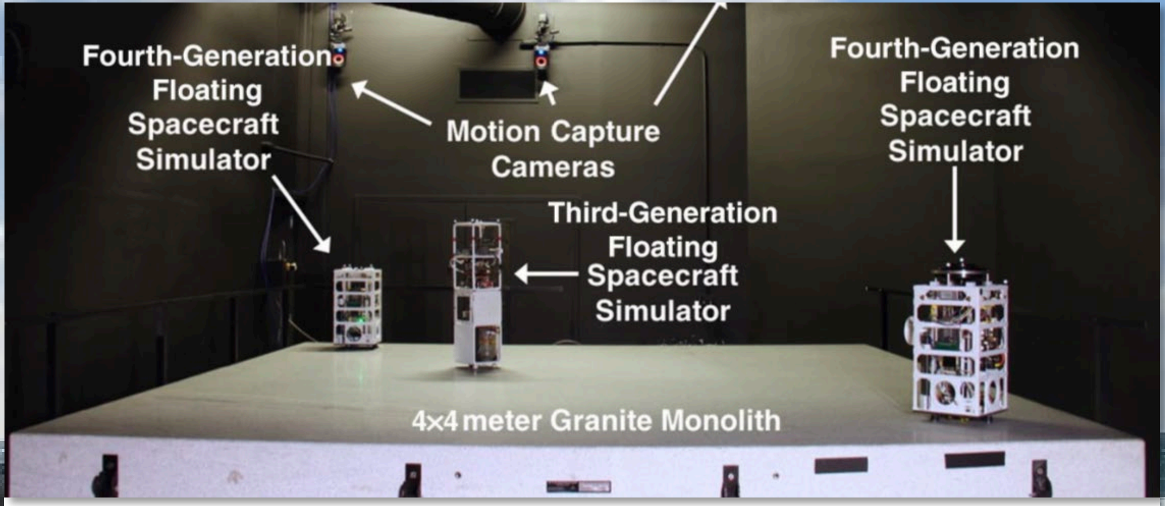
Naval Postgraduate School

Spacecraft Robotics Laboratory and Research Team (founded 2004)



Proximity Operation of Spacecraft: Experimental hardware-In-the-loop Dynamic Simulator (POSEIDYN) Testbed

How

- The **research approach** of the Spacecraft Robotics Laboratory (SRL) is to use a combination of theoretical and analytical development, numerical simulations, and experimental testing.
- The **teaching approach** is to bring research topics at the forefront of astronautical engineering and orbital robotics to the classroom and to provide students with hands-on educational experience on spacecraft-like systems (dynamic spacecraft simulators maneuvering in a laboratory environment).

Recent and ongoing projects

- Modeling and Simulation Environment for Comparative Analysis and Synthesis of Distributed Space Logistics Missions (Sponsor: DoD)
  - Modeling and comparative analysis of emerging space architectures that include on-orbit servicing, orbit modification, and modularity
- Dynamic Modeling and Control of a Space Based Solar Power Satellite (Sponsor: DoD)
  - Dynamic modeling and control of a large artificial satellite for the collection of solar light energy and retransmission to specific locations on the Earth surface
- Differential drag control of two satellites in LEO (Sponsor: US Navy)
  - Modeling, control design, simulation and flight experiments
- Optimal relative maneuvering of orbiting satellites (Sponsor: DoD Space)
- Astrobatics (Sponsor/Support: NPS Foundation / NASA / Space Test Program)
  - Advanced maneuver experiments with the Astrobee free-flyer on the International Space Station

Why

- Coursework and thesis projects prepare students for future work with orbital robotics, space systems engineering, spacecraft GN&C, and autonomous vehicles.
- The SRL developed and hosts unique, state-of-the-art facilities that allow hardware-in-the-loop experimentation and testing of autonomous spacecraft guidance, navigation, and control (GN&C).
- SRL research supports DOD and civilian space agencies in mission design, software algorithm development, and analysis of operational spacecraft.

Success Metrics

- Students graduated: > 40 M.Sc., 8 Ph.D., 8 NRC Postdoc
- Selected alumni: 5 faculty, 6 senior engineers in government & top space companies
- Publications: > 60 journal papers, 9 awarded patents
- Research grants attracted: > $7.5M

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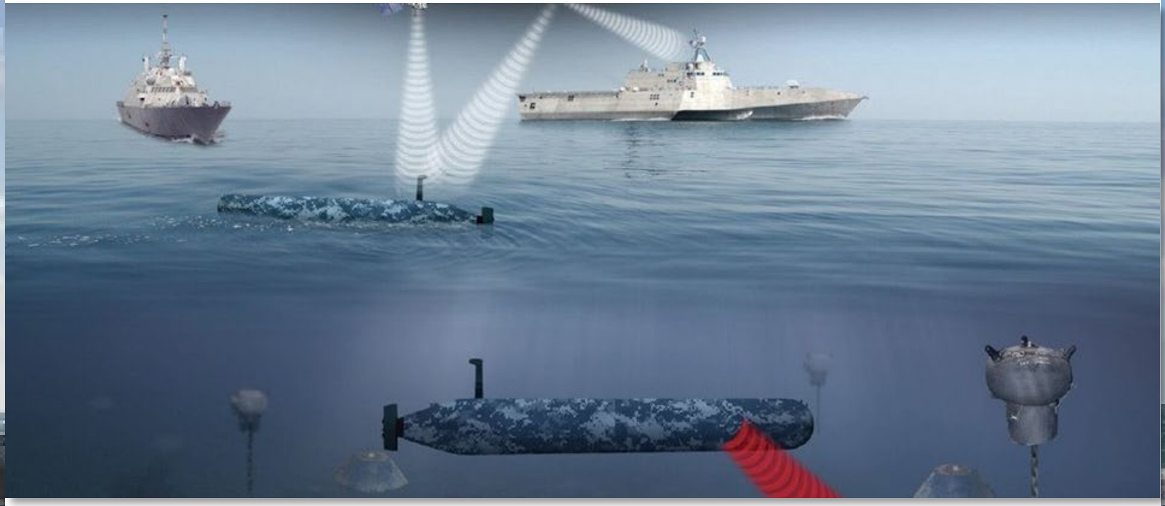
Naval Postgraduate School

Deterministic Artificial Intelligence
Applied to LUSVs, UUVs, UCAS and MUOS



How

- Continue development of award-winning methods recently proposed for UUVs, spacecraft, DC motors and electronic circuits
  - **UUVs**: https://doi.org/10.3390/jmse8080578
    - *Originally seeded by SecNav-chartered Consortium for Robotics and Unmanned Systems Education and Research (CRUSER)*
  - **Spacecraft**: https://doi.org/10.3390/a13010023
  - **DC Motors**: https://doi.org/10.3390/app11052144
  - **Circuits**: https://doi.org/10.3390/math5040070

What

- Develop fully-autonomous recovery from battle damage and accomplish mission in contested environments despite significant damage without human intervention
- Be able to communicate updated physical math models to home base afloat and/or ashore without mission interruption

Why

- Operational Impact: new capabilities will extend well beyond the effectiveness of standalone platforms or human-centered systems to transform naval warfare by providing asymmetric advantages to each and every Sailor and Marine.

To compete and win in an era of great power competition, the Department is committed to investing in advanced autonomy, robust networks, and unmanned systems to create true integrated human-machine teaming that is ubiquitous across the fleet – SecNav, 2021

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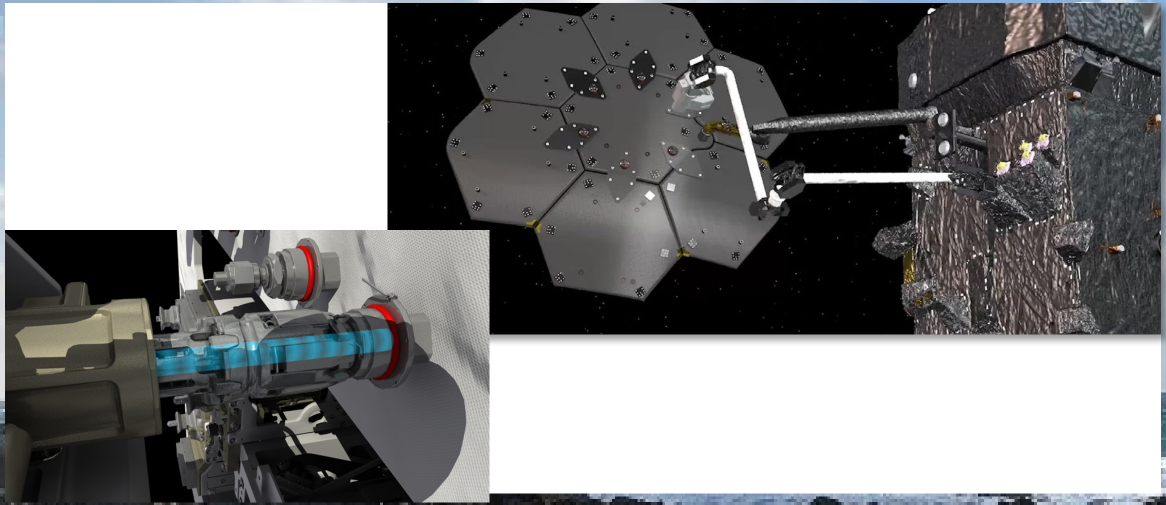
School

Space logistics and mobility supporting US Space Force



How

- Develop techniques for highly flexible, lightweight space robots to perform in-situ repair and resource replenishment from CisLunar space
- Develop CisLunar service/supply stations options
- Develop new supply chain management concepts

What

- Fully-autonomous supply chain (repair and resupply) from CisLunar orbits
- Modify orbit to intercept and grasp and lower earth orbiting satellite and perform repair and refueling operations
- Return to CisLunar supply station to prep for next servicing/resupply mission

Why

- Newly enhanced space mission lifecycle can eliminate/delay the need to replace capabilities at typical spacecraft end-of-life

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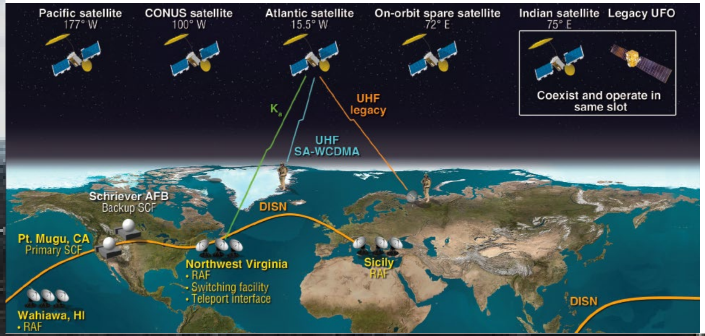
D.A.I. augmented with constrained optimization for Navy SysCom



What

- Fully-autonomous non-stochastic A.I. methods requiring no training data
- Reduced computation burden with non-numerical constrained optimization
- Increased system robustness with optimal learning

How

- Integrate two state of the art methods
  - Deterministic artificial intelligence (D.A.I.)
  - Constrained nonlinear optimization
- Use full-order, high-fidelity models without approximation, yet reduce computational burden
- Use analytic methods to further reduce burden

Why

- Operational Impact: new capabilities will extend well beyond the effectiveness of standalone platforms or human-centered systems to transform naval warfare by providing asymmetric advantages to each and every Sailor and Marine.

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