The Southern Maryland Initiative for Energetics Capability Development

Annual Report

January 3, 2011

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Foreword

This *Annual Report FY11* provides an overview of accomplishments, ongoing activities, and future plans of the CECD/ETC Enterprise in Southern Maryland. It is the seventh in a series of documents for the *Southern Maryland Initiative for Energetics Capability Development: A Response to Emerging National Needs.*

The Energetics Technology Center (ETC) was established *to be a catalyst for research, development, prototyping, education, and training in Southern Maryland and to facilitate, in partnership with the Naval Surface Warfare Center Indian Head Division (NSWCIH), Southern Maryland becoming a world class Center of Excellence in Energetics*. This need for energetics and energetic systems arises from two pressing issues, both critically linked to U.S. national security: the first to regenerate the energetics professional workforce and the second to develop ever more sophisticated systems in a timeframe that will ensure that the Department of Defense has the state-of-the-art capabilities.

The CECD/ETC team, working with NSWCIH and other entities, conducts a wide range of scientific and technology activities, policy/planning studies, and workforce development programs to advance the development of energetic systems and recapitalize the nation's energetics workforce. To further strength our activities and extend our reach, a cooperative agreement with ARL, similar to that with NSWC IH, was signed in 2010.

The CECD/ETC team has met all the milestones established in the FY10 and earlier plans. The ETC is now a fully functional non-profit organization with 14 full-time employees and 15 part-time employees and consultants. Currently, CECD and ETC are working on a number of projects supported by NSWCIH and ONR. These are in the areas of nanotechnology, energetic materials, virtual environments, energy, traumatic brain injury, and workforce development. Some examples of our current work are included in this report.

Southern Maryland has a long history of contribution to the field of energetics development for ordnance applications. The base at NSWCIH has been a leader in Navy ordnance development and testing for over 100 years.

The United States Congress has provided funds for programmatic support of the ETC and enhancing the work of the CECD. These funds have been crucial to achieving our objectives in establishing Southern Maryland as an Energetics Hub. The continuation of this support is vital for growing a strong presence in this field and, in partnership with NSWCIH, establishing a world class Center of Excellence in Energetics.

Davinder K. Anand
Professor and Director
CECD

Robert Kavetsky
Executive Director
ETC

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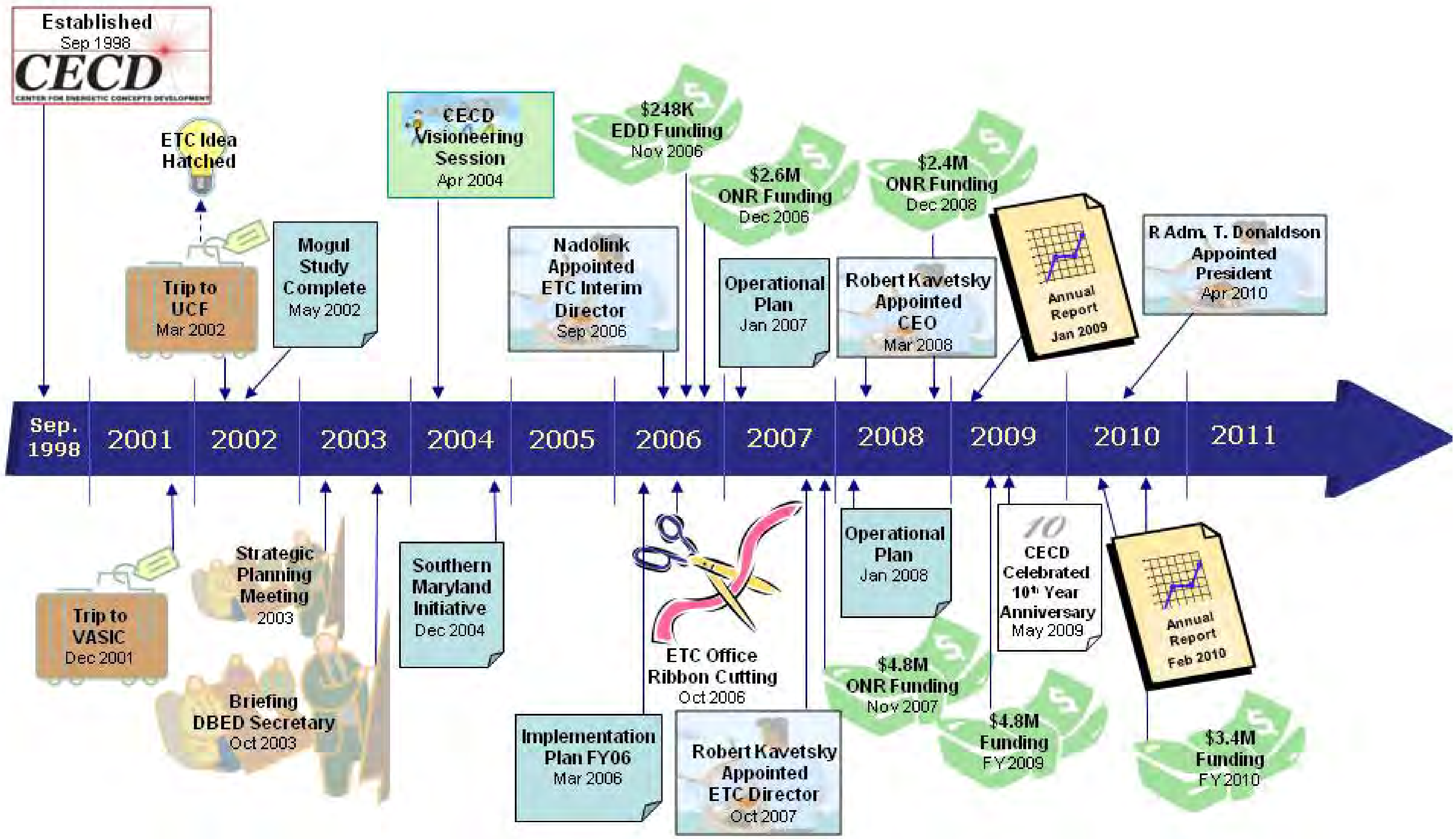
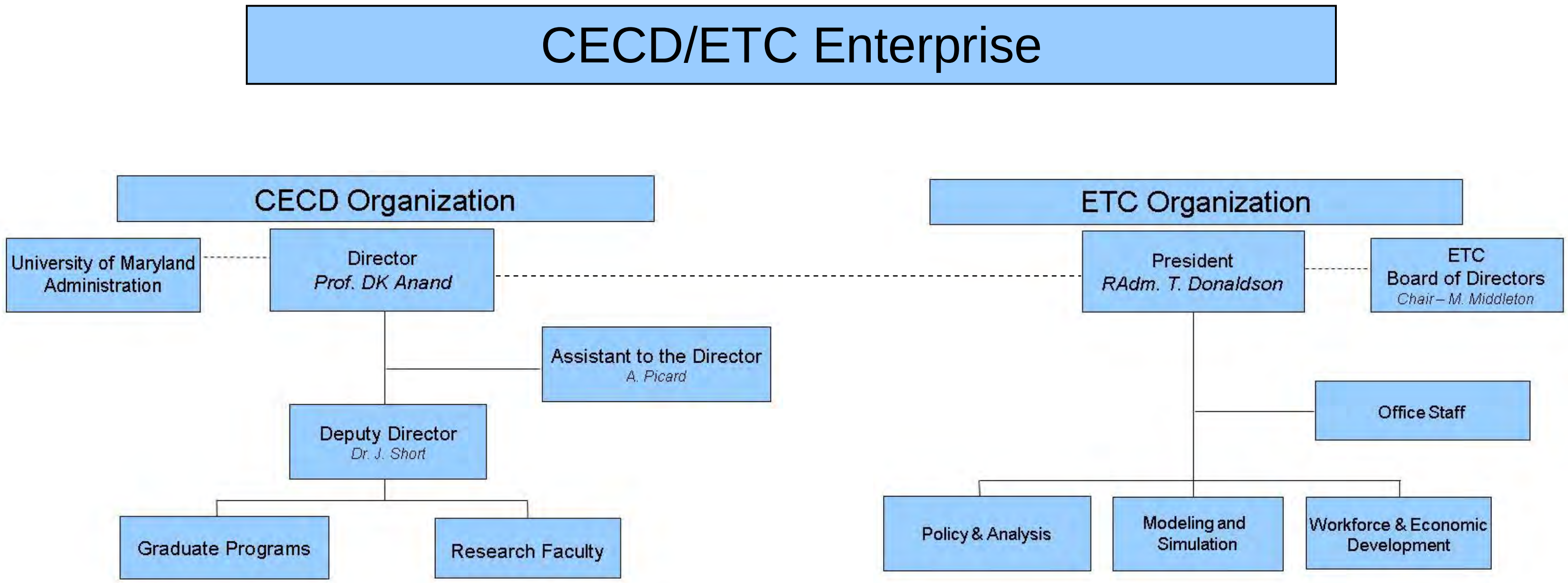
Growth of the CECD/ETC Enterprise





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Workforce & Economic Development

Contract Performance

A Simulation Based Framework for Synthesizing Action-Selection Policies for Autonomous Unmanned Surface Vehicles

A major issue in the development of increased autonomy for robotic vehicles such as USVs is the time and expense of developing the software necessary to handle a large variety of missions and all the variations in the encountered environments. This is a challenging task and requires writing hundreds of thousands of lines of code by human programmers.

We have developed a new approach for developing planning software that operates autonomous USVs. This new approach takes advantage of the significant progress that has been made in virtual environments (VE) and automated synthesis. The basic idea behind our approach is as follows. The USV explores the VE by trying different moves. USV moves are simulated in the VE and evaluated based on their ability to make progress toward the mission goal. If a successful action is identified as a part of the exploration, then this action will be integrated into the policy, driving the USV.

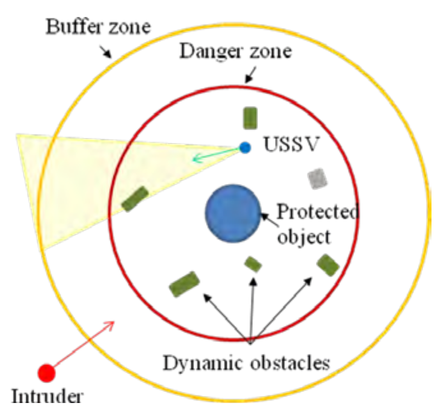
We anticipate that there may be portions of the mission, where exploration alone will not be adequate to discover the right decision rules. In such cases, two additional approaches are utilized to make progress in acquiring the right policy. The first approach involves seeding the system with the policy employed by humans to solve a challenging task. The second approach is to restrict the action space based on some type of feasibility criteria.

We focus specifically on automated generation of action selection policy used for blocking the advancement of an intruder boat towards a valuable target. The first major component of our approach is development of a physics-based meta-model. High fidelity simulation of USV is computing-intensive and cannot be used for discovering decision rules or trees used in planning. We have developed a meta-model by conducting off-line simulations of the USV in the sea. This simulation accounts for wave and USV interactions.

We have developed a mission planning system whose main part is an evolutionary module for evolving action selection policy decision trees. We used this system to automatically generate decision trees expressing blocking policy for the USV. This means that instead of automatically generating a program composed of low-level controller actions, we generate a program represented as a decision tree that consists of high-level navigation commands as building blocks together with conditionals and other program constructs.

We have developed a VE-based visualization system, which serves as an emulator of the real USV environment and allows human players to play against each other or against the computer. In the game, the player controlling the intruder boat must reach a protected target, while the player controlling the USV must block and delay the intruder as long as possible. The game can be played on two computers over a network. In addition to offering basic gaming capabilities, the visualization system provides collision detection and basic physics to the objects in the scene. Our results show that the policy automatically discovered by the system performs at par with the policy designed by an experienced human programmer.

Virtual environment for simulation



Simple mission: USV protects area containing the target

Contract Performance

Nanotechnologies for Trace Explosives Detection

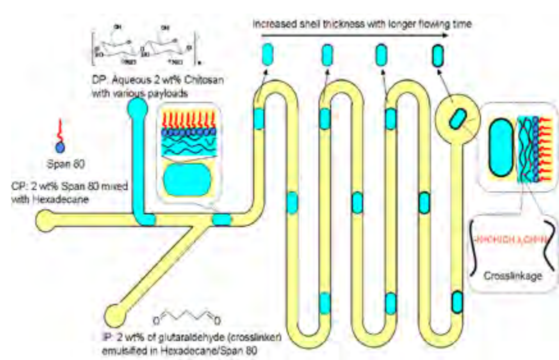
Due to the "concentration gap" between the vapor pressure associated with trace amounts of explosives and the sensitivity limits of both established and emerging detection modalities, there remains a strong need for new technologies, enabling the effective concentration of trace explosives from a variety of environmental sources (air, water, surfaces, etc.). Existing concentration technology is generally based on the use of polymer materials, typically in the form of ~100 µm beads, and often with affinity agents used for selective sample capture. As part of our overall efforts to realize novel nanotechnology-enabled materials for label-free and real-time trace explosive detection, we are developing a new porous microparticle technology with the aim of realizing concentration factors of 10^4-10^5, at least 2 orders of magnitude higher than established technologies, with the goal of achieving trace analysis of parts per quadrillion (*ppq*), making the technology suitable for the detection of buried munitions vapor by surface acoustic wave or microcantilever sensors.

In our previous efforts, we explored the development of functionalized nanoporous materials as novel surfaces for ultrasensitive analysis of adsorbed explosives by surface-enhanced Raman spectroscopy (SERS). In this work, we demonstrated the use of nanostructured porous surfaces with high specific surface areas for enhancing analyte adsorption and increasing SERS signals through optical interactions with the structured substrates. Techniques for covalently attaching metal nanoparticles to the porous materials were developed as a robust alternative to simple physical adsorption used in many existing SERS systems. Three specific material systems were explored in this effort, namely polymer monoliths, nanofilament silicon dioxide, and porous anodic alumina. Leveraging this background, we have recently focused our attention on the fabrication of porous glycol methacrylate (GMA) polymer monolith microspheres. An SEM image of a typical microsphere is shown below. Unlike traditional explosive concentration particles with smooth surfaces based on polydimethylsiloxane (PDMS) polymer, the particles possess a highly porous morphology with large surface area for efficiently adsorbing analyte molecules, and we have demonstrated the ability to covalently anchor antibodies to the GMA surface for selective capture of nitrotoluene explosives, for example using cysteine as a capture probe.

The unique monolith microparticles are synthesized using a microfluidic technique similar to the one depicted below. Particles with tunable geometry can be readily fabricated, with exceptionally low polydispersity achieved by leveraging the controllable flow physics within the microfluidic system.

Once fabricated, the microspheres may be functionalized on-chip for the specific sensing application. We envision that the fabricated porous microspheres will be applied to a SAW or microcantilever sensor surface, with enhanced mass loading resulting from the highly porous structures, while the multiscale flow paths between and within the beads will ensure rapid diffusion of explosive vapor into the structures for efficient sample concentration.

SEM micrograph of a GMA polymer monolith microsphere



Schematic of a microfluidic technique for the synthesis of monodisperse particles

Contract Performance

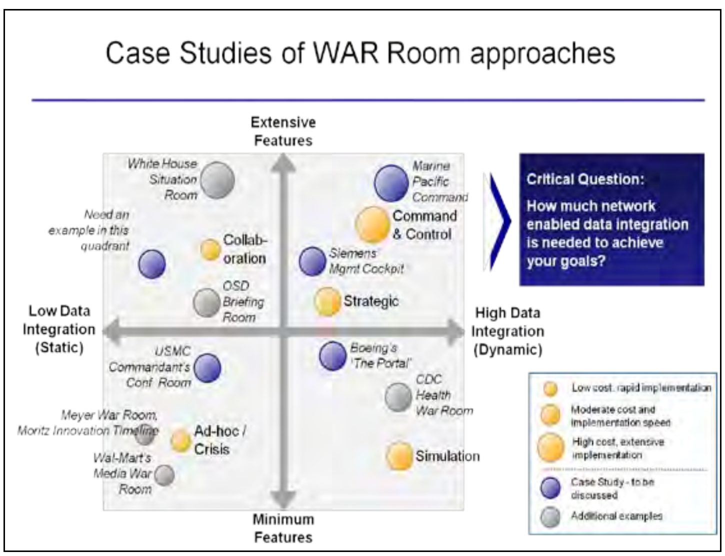
Policy and Strategic Planning

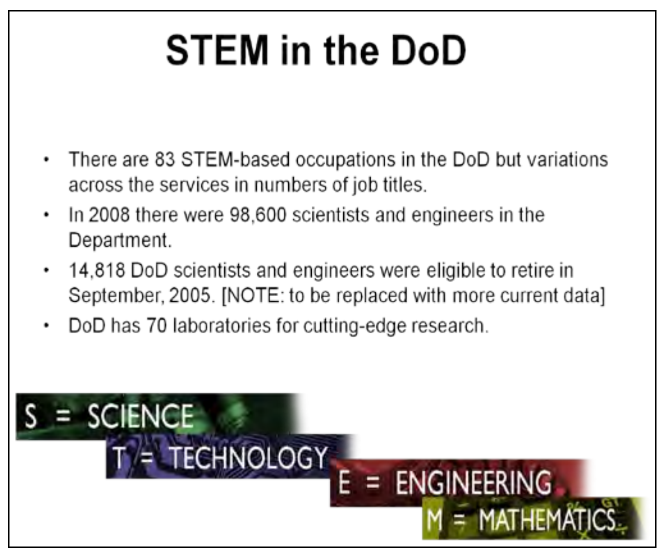
ETC is supporting two DDR&E organizations, and the Assistant Secretary of the Navy's office, which collectively provide critical leadership regarding DoD and the Department of the Navy (DON) Laboratory issues, and Science, Technology, Engineering and Mathematics (STEM) activities for the Department of Defense.

For the Defense Laboratory Enterprise effort, a key element of this past year's program was conducting a pilot study of a critical in-house DoD lab technology capability. The technology area chosen was energetics, and a thorough analysis of the DoD's capabilities in energetics was conducted. Next steps in the analysis will be to bore in on critical personnel and staffing issues, as well as addressing the global situation regarding energetics research and development.

For the STEM Development Office, ETC is developing a "STEM Enterprise Intelligence" approach to creating and using manpower and service outreach and education program information to help shape the DoD's STEM portfolio. This will enable DDR&E leadership to use a data-driven approach to filling critical future science and engineering positions in the Department.

For the ASN Principal Civilian Deputy, ETC is developing options for a decision support center that would be used for senior DON officials to evaluate and assess personnel, facility and funding information in a timely and consistent fashion. Of particular importance is developing a set of key indicators for Navy's the acquisition workforce, to ensure the appropriate workforce is hired and developed with the necessary skills sets over the next 10 years.





Contract Performance

High Energy Launch Systems and Projectiles

Energetic materials and high-energy explosives offer the possibility of boosting payloads at very high accelerations, specifically to cover long ranges on earth's surface. In particular, energetic materials derived from nano-particle formulations can yield very high initial launch velocities, enabling ballistic systems with very far reach. Similarly, electromagnetic launch systems currently under development with both the U.S. Navy and U.S. Army hold the promise of gun systems that can launch massive projectiles with high initial velocities.

A key element in the effective use of such systems is the efficient aerodynamic design for an object that will be accelerating to very high speed in a relatively dense portion of the atmosphere, then cruising with minimal drag losses. The aerodynamic forces on an object are proportional to the local air density and the square of the velocity; power required to fight that drag scales with the cube of the velocity. Thus, there is considerably more drag on an object that begins low in the atmosphere at high velocity, as compared to one that with smaller acceleration. Emerging from a gun barrel at extreme initial velocities will also include significant initial drag unless the object is carefully designed. With poor performance, a significant fraction of the initial energy can be lost, reducing the range and negating the benefits of the high-energy system.

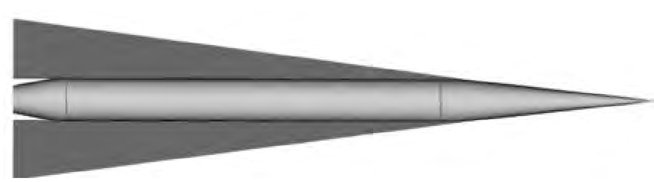
The emphasis in the second year of this study has been to optimize the aerodynamic design of a high-energy gliding projectile to maximize range. The projectile is assumed to be launched at high acceleration in a low drag configuration, deploy wings upon reaching apogee, and glide in a high lift to drag ratio configuration for the remainder of the flight. As a result, the projectile must be able to fly efficiently across a very wide range of speeds and altitudes.

A multi-variable constrained optimization method based on the Broyden-Fletcher-Goldfarb-Shanno method (BFGS) has been applied to solve for both the best morphing projectile geometry, and the associated optimal trajectory. A projectile with the capability of changing between two or three different discrete geometries would have the balance between manufacturing feasibility and optimality. An example of such a projectile wing design would be to optimize a scissor wing projectile. A scissor wing projectile would have two different configurations, one of low aspect ratio for a the supersonic flow regime.

The projectile design assumes launch at supersonic speeds. It then flies its trajectory through transonic, then subsonic speeds. Having those three speed regimes in the flight envelope means that the aerodynamic modeling must take into account several different considerations. For the supersonic regime, a potential sonic leading edge condition was modeled. The transonic regime experiences highly non-linear aerodynamics. Vortex lift must also be accounted for, a factor not often included in projectile aerodynamics. This has been analytically, since a CFD analysis for every potential geometric configuration throughout the optimization would incur huge computational expense, especially with a coupled trajectory solution. Ultimately, a CFD analysis will performed on the "best" derived configurations.

LOW DRAG:

HIGH L/D (WINGS DEPLOYED):

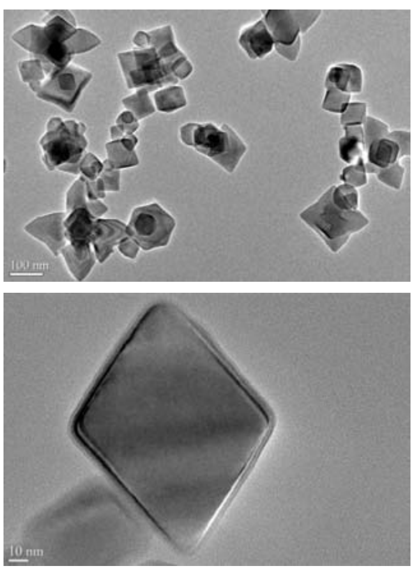


Morphing projectile forms for optimal flight across a Mach spectrum

Contract Performance

Aerosol Based Production and Passivation of Submicron Aluminum Particles

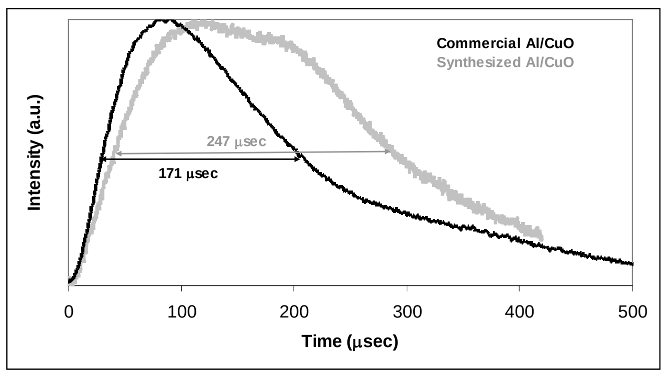
We show a low temperature gas-phase synthesis route to produce faceted aluminum crystals in the aerosol phase. Use of triisobutylaluminum whose decomposition temperature is below the melting point of elemental aluminum enabled us to grow nanocrystals from its vapor. TEM shows both polyhedral crystalline and spherical particle morphologies, but with the addition of an annealing furnace one can significantly enhance production of just the polyhedral particles. The results on surface passivation with oxygen suggest that these nanocrystals are less pyrophoric than the corresponding spherical aluminum nanoparticles. The figure below shows the formation of such particles.



TEM images of Al nanocrystals

To test for reactivity of the polyhedral crystalline particles, samples were combined with stoichiometric CuO and burned in a pressure cell. The resulting optical response is compared to a response from commercial aluminum/CuO in the figure below. The broader peak for the synthesized aluminum suggests that either the polyhedral crystalline particles ignite at a higher temperature after the spherical particles in the sample have started burning, or the polyhedral particles actually have longer burn times than standard nanoaluminum. This result is consistent with the previous observation that the polyhedral crystal particles were not as pyrophoric as spherical particles produced with our system. The enhanced stability of these particles can be attributed to the higher surface binding energy for molecules on a flat surface compared to that of a curved surface due to the Kelvin effect

Pressure response from these experiments showed a maximum pressure rise of 166 psi for the synthesized Al compared to a value of 116 psi for commercial product, both with similar rise times. The polyhedral particles thus yield a significant enhancement in reactivity. This information combined with the optical and experimental observations lead to the conclusions that we have produced polyhedral nanoaluminum particles with both enhanced stability and increased energy release.



Optical response from combustion of commercial (black) and synthesized (grey) aluminum with stoichiometric CuO in pressure cell test

A paper on this work is currently in press:

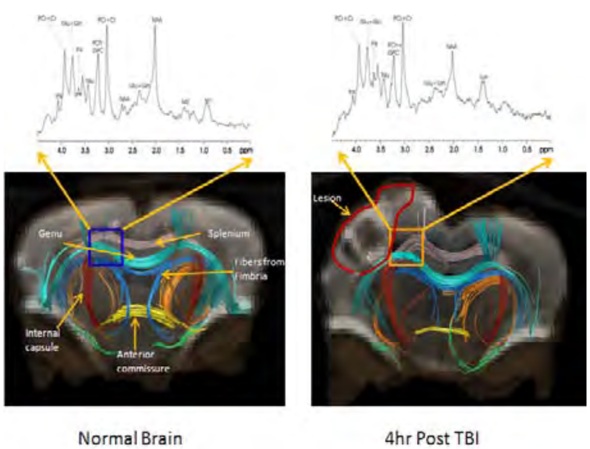
D. A. Kaplowitz, R. J Jouet, and M. R. Zachariah "Aerosol Synthesis and Reactive Behavior of Faceted Aluminum Nanocrystals", *Journal of Crystal Growth,* in press.

Contract Performance

Non-invasive Imaging of TBI

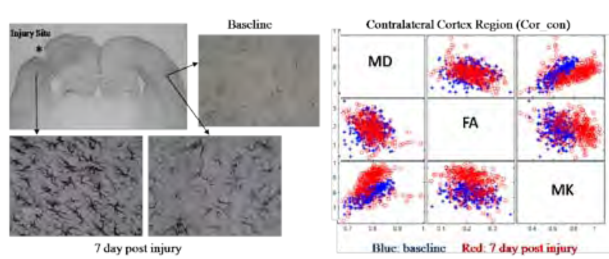
The relatively mild non-penetrating TBI caused by blunt force or blast is neuroanatomically subtle, with little or no structural alterations that are apparent using standard imaging techniques including with CT and conventional MRI. Considering the enormous complexity of the delicate white matter fiber tracts responsible for information transfer within the brain, it is likely that selective disruption of these pathways occurs following TBI. Disruption of these pathways can be quantitatively analyzed through the use of diffusion tensor imaging (DTI) and functional connectivity experiments. Moreover, MR spectroscopy (MRS) can be used to identify subtle but important alterations in cerebral energy metabolism that may that may precede any neuroanatomic structural change.

Experimental animal models such as controlled cortical impact injury (CCI) are useful for understanding the cerebral microstructure and metabolic mechanisms of brain cell death and neurologic impairment that occur in various forms and intensity of human TBI and results from these studies can be compared with animals exposed to blast injury.



The figure above demonstrates the changes in the MRS metabolites and DTI changes before and 4 hours following CCI. The spectra clearly demonstrate a marked reduction in N-acetylaspartate, a quantitative marker for neuronal integrity at the site of the injury. In addition we find a marked reduction in glutamate, an excitatory neurotransmitter which may explain some of the behavioral differences we see among the injured rats. In a few animals we also observe a severe increase in lactate as shown above indicating an increased energy demand. Concurrently, the DTI related parameters such as fractional anisotropy (FA) and apparent diffusion coefficient (ADC) were significantly altered in the ipsilateral region. At 2h after injury, ADC was significantly reduced and FA increased ($p<0.05$) in the ipsilateral hippocampus and the thalamus. A trend for ADC reduction was observed bilaterally in the thalamus and the ipsilateral olfactory region ($p<0.1$). For FA, an increasing trend ($p<0.1$) was also observed for the contralateral hippocampus. These observations were also made at 4 hours and along with an increased involvement of the contralateral thalamus. Both the MRS and DTI results indicate a window of opportunity for intervention to be about 3h for planning interventions that might limit secondary damage to the brain.

We have developed a new technique that is sensitive to inflammation following mild traumatic brain injury. Such an injury is subtle and is difficult to pick up using standard MRI or even DTI techniques. The technique, called diffusion kurtosis, is sensitive to the distribution of water diffusion as the tissue undergoes increased immune reactivity indicative of astrocyte activation in response to the CCI injury. Such changes are sensitive to diffusion kurtosis and not FA or ADC as shown in the cortex in both hemispheres in the figure below. Increased kurtosis in the contralateral hemisphere also correlates with increased immunoreactivity compared to the baseline. We expect this increased sensitivity to mild TBI will allow us to better characterize blast TBI related injuries in vivo in our future MRI experiment.



Histology shows increased astrocyte activity in ipsi- and contra- lateral side cortex compare to baseline (left). A pair-wise scattered plot of diffusion and kurtosis parameters. or voxels within the contralateral cortex re same rat was also shown (right).

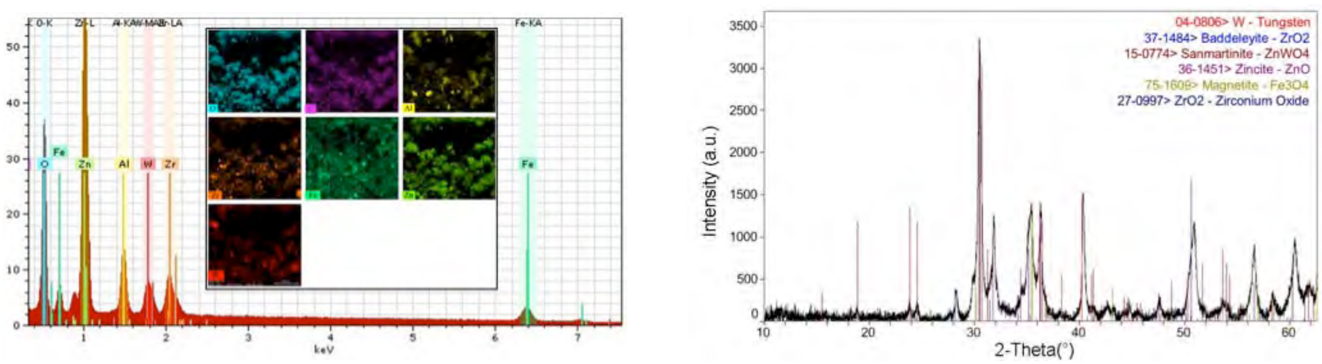
Contract Performance

Debris Characterization for NSWCIH Reactive Materials Program

This project required evaluation of reactive material (RM) debris resulting for test shots in the NSWCIH test facility. During RM shot experiments, one-quarter inch thick lexan covers were used to protect the inside faces of the translucent octopig windows. These lexan covers also served as post-anvil impact debris collection plates for each shot. After each shot experiment these plates (with embedded debris) were collected for powder X-ray Diffraction (XRD) and Scanning Electron Microscopy (SEM) analysis. For particular shot experiments, one-half inch thick lexan plates were used in place of steel as anvils in order to trap projectile fragments for analysis after passing through the octopig skin.

A Bruker C2 Discover (Parallel Beam) General Area Diffraction Detection (GADDS) system was used for measurement of powder diffraction profiles. A monochromatic Cu Kα radiation source (40 mV and 40 mA) was employed along with Bruker ACS Hi-Star detector. Electron Microscopy coupled with Energy Dispersive X-ray Spectrometry (EDS) was performed using an Ultra-High Resolution Hitachi SU-70 Analytical Scanning Electron Microscope (UHR FEG-SEM) equipped with Bruker's silicon drift detector (SDD) for elemental analysis. All analytical data were performed at the University of Maryland, College Park.

Experiments were designed to probe materials behavior and particle size dependence in RM mixtures of shots. After firing, metallic Zn and W are still present, however if any metallic Zr exists it is difficult to discern in low concentrations due to peak overlap with other phases. The differences in residue composition from these two shots undoubtedly demonstrate a substantial difference in reactivity that is dependent on the Zr particle size. Similar data was collected for residue from a similar projectile (RM08-121) at 2000 ft/sec. As expected, the results were identical to the RM08-139 projectile residue.



(Left) EDS data with inset showing SEM elemental phase mapping; (right) Powder XRD profile of RM08-44 shot experiment debris

Contract Performance

Workforce Development/STEM Focus

Our Workforce Development activities continue to be focused on Science, Technology, Engineering and Mathematics (STEM) and are carried out at four primary levels:

- Graduate level education in energetics.
- Summer internships at NSWCIH, NAWC Patuxent River, NASA, and ETC
- The Energetics Scholarships Program at the College of Southern Maryland
- Community STEM programs, such as Robotics Competitions and the Youth Technology Summit.

In collaboration with the University of Maryland's Office of Advanced Engineering Education, the CECD offers to Indian Head (and others) a Masters of Engineering in Energetic Concepts and a Graduate Certificate in Energetic Concepts. Courses are available to Indian Head employees free of tuition. Both the masters degree and certificate can be achieved with courses available online.

Our summer internship program is designed to attract diverse, highly motivated students to careers in energetics. During the summer of 2010, ten students interned at six different organizations.

The Energetics Scholarship Program at CSM completed its fourth year and currently involves 36 students. Twelve of the fifteen students of the first Cohort have transferred to a 4-year university. The quality of students entering the third Cohort is extremely impressive with a 3.7 average GPA. Ninety-five percent of the remaining students in the program intend to continue their education at a four-year university in Maryland.

CSM Energetics Scholarship students

We have sponsored CSM's Robotics Competition and supported the Youth Technology Summit, which inspire and entertain over 700 students annually.

ETC sponsoring awards at the 2010 Robotics Competition

Contract Performance

Energetics Materials Research

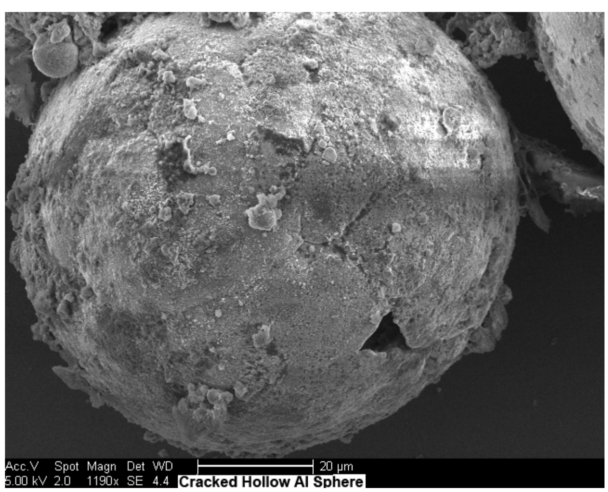
This past year's focus has been designing specific experiments to measure the aluminum-water reaction rate and energy release for various stress states for the very first time. These experiments will be done using a special gas gun to shock load the energetic composite material of aluminum micro-balloons and water. The micro-balloons provide pure aluminum surfaces and large amounts of heat aftershock compaction, which assists its reaction with water.

ETC has contracted with the University of California-San Diego (UCSD) to develop a spark-erosion technique for making the aluminum micro-balloons.

Modeling reaction of shocked materials is done using numerical hydrodynamic codes that solve conservation of mass, momentum and energy equations for a shocked system. For the code to work, it needs to know how a material compresses under shock loading. This is defined by thermodynamic equations of state. ETC developed an equation of state for shocked porous aluminum for Applied Research Associates, SWD to use in their blast wave SHAMRC code. This equation of state included the solid and the melted phases of aluminum.

ETC has provided support to NSWCIH scientists in conducting testing in explosive test facilities, such as in the research laboratories, explosive test chambers/ bombproofs and gun facilities. These experiments require specialized data acquisition from high-speed cameras, gauges, velocity pins, and high-speed storage oscilloscopes.

Another area where ETC is assisting NSWC-IH is material characterization tests at NSWCIH using a Split Hybrid Hopkinson Bar to rapidly compress soft materials. This information will be used to assess what occurs in soft material such as the brain when a blast shock wave passes through it.



Hollow aluminum micro-balloons
(Scanning Electron Microscope image)

Contract Performance

Bomb Proof Studies

We supported NSWCIH researchers on detonation science studies. The programs supported included, but were not limited to:

- **Defense Advanced Research Projects Agency (DARPA)** *Reactive Materials*
- **Office of Naval Research (ONR)** *Reactive Materials*
- **Defense Threat Reduction Agency (DTRA)** *High Energy Composite Explosive Program; Agent Defeat; Modified Wedge Testing*

Support was provided in the way of test setup, data collection, analysis, and scientific publications.

The main research focus of the DARPA reactive materials program was to assess the reactivity of cylinder casings with the density of steel. Testing was completed in a mid-sized closed bomb chamber outfitted with XTE Kulite pressure gauges.

The cylinder was reacted using high explosive and a detonator. The blast pressure was recorded for one half second, at a million frames per second. From this record the peak quasi-static pressure and time of burning could be analyzed.

Cheetah (Thermo-Chemical Computer Code) was used to find the theoretical 0% to 100% peak quasi-static pressure by adjusting the amount of components in the reaction. Combined with post shot residue analysis, a relative percent of components burned in the reaction was found.

DTRA's High Energy Composite Explosive testing proceeded in the same manner, but a smaller octagonal closed bomb chamber was used. The main research focus for this program was to develop a new reactive casing material that would react upon detonation and enhance the overall blast pressures.

When an explosion occurs in a confined space, the heat of reaction is initially contained in the reaction products as they expand. Any existing atmosphere is compressed and mixed to some extent with the reaction products. Mixing not only distributes the heat but also allows any remaining fuel in the products to combust if the atmosphere contains oxygen. These processes are slow relative to the detonation of the explosive; therefore the peak quasi-static pressure is reached after the initial rise in the pressure pulse inside the bomb chamber.[1]

Results from pressed materials were compared with solid fuel and mild steel cylinders of the same configuration. Estimates of energy release from each reactive casing were determined from peak quasi-static overpressures and then compared with theoretical calculations from Cheetah.

Mid-sized closed bomb chamber

1. Granholm, R.H. and Sandusky, H.W., ***Calculation*** of Internal Blast Pressure, Proceedings of 2008 JANNAF Combustion Subcommittee Meeting, May 2008.

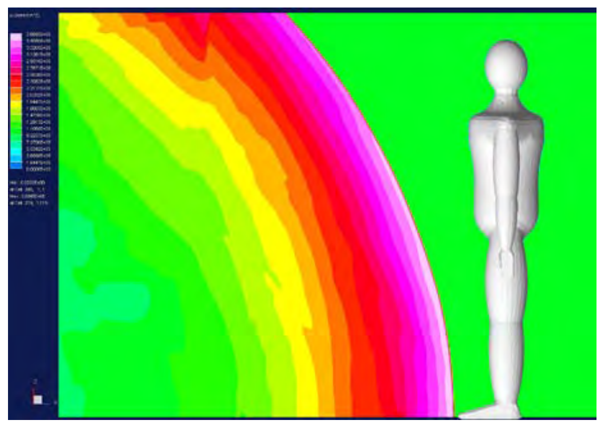
Contract Performance

Traumatic Brain Injury (TBI) Modeling and Simulation

ETC, CECD, University of Maryland School of Medicine and NSWCIH are working together on creating an accurate simulation of a shockwave, created by an explosive, hitting and propagating through a human body with a focus on the head. To create this simulation, we are using an advanced Navy program called DYSMAS (Dynamic System Mechanics Advanced Simulation). It is a coupled-code program that can run Eulerian code and Lagrangian code in tandem. By using an Eulerian code, it is possible to create an accurate simulation of the shockwave being created by the explosion and propagating though the air. By using a Lagrangian code, it is possible to create an accurate simulation of how the body reacts to the shockwave hitting and propagating through it. Once an accurate simulation is created, we will be able to determine where the most stress or strain is created due to the shockwave. We will then be able to predict damage caused to the body.

In order to determine if the simulations created are accurate, work has been done to relate the DYSMAS predictions to experiments conducted by the University of Maryland School of Medicine. In a separate study, UM has been simulating the creation of TBI by exposing laboratory animals within a container to a sudden increase of acceleration caused by a small explosion. To create a virtual simulation of their experiments, Magnetic Resonance Imaging (MRI) and X-ray Computed Tomography (CT) scans of the animal's body were made to obtain high resolution images. With these images, a finite element model was created by using a converting program called Simpleware. The finite element model was then put inside a model of the container which is then exposed to a sudden increase of acceleration like that experienced in the experiment.

To have a better understanding of what happens to the overall body during a blast, a 3D model of the human body was created in ProE (Pro/Engineer). The model was then run through a program called Femap that converts the model from a CAD model into a finite element model, which is the necessary format need to run within DYSMAS. A simulation of the body experiencing a shockwave propagating through it was then created. This simulation consisted of a 15 pound TNT explosion affecting a body at a distance of 15 feet away. The DYSMAS system was set to output recordings of displacement, force, acceleration, stress, and strain at a series of predetermined points along the model. This enables a better understanding of what is happening to the model during the simulation.



DYSMAS modeling of TBI

Contract Performance

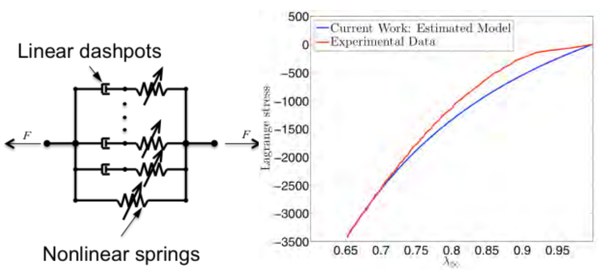
Blast Wave Interactions with Soft Tissue Matter

The interaction of blast waves with the human head involves propagation of nonlinear stress/strain waves within the brain, and this propagation is characterized by the transfer of a large amount of energy at high strain rates in a short time window. Experiments with swine and rat brain tissue subjected to tension, compression, and shear loads indicate that brain tissue behaves as a nonlinear visco-elastic material. Brain tissue material nonlinearities and heterogeneity are likely to produce localization of stresses and strain, and this localization may help understand mechanisms of brain injury.

The current studies have been carried out with the aim of developing reduced-order models to aid the following: i) obtain fundamental insights into wave propagation phenomena in the skull-brain system, ii) understand the influence of nonlinear visco-elastic properties on the dynamic behavior of rod-like structures, and iii) experimental characterization of soft tissue.

The accomplishments for this year include the following:

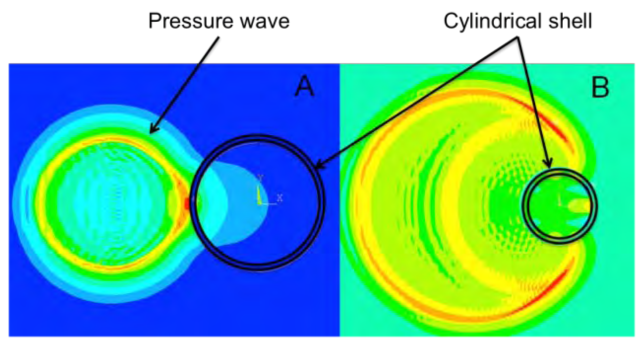
1) Development of a basic non-linear visco-elastic model to mimic brain tissue behavior. The model parameters can be adjusted with available experimental data.



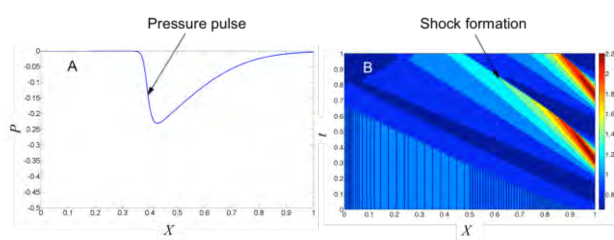
Nonlinear visco-elastic model and comparison between experimental data and estimated model responses

2) Numerical simulations of the interaction between acoustic pressure waves and cylindrical fluid filled shells were carried out by using ANSYS®. Simulations confirm the fact that external pressure waves do get through the skull and produce pressure oscillations in the brain matter.

3) Development of a continuous nonlinear viscoelastic rod model to study wave propagation along brain fibers with aim to uncover nonlinear mechanisms such as energy localization and shock waves that could potentially lead to brain tissue damage. Understanding of the effect of load amplitude and frequency in the wave propagation phenomena could provide knowledge that can be used in the design of more effective protective equipment.



(Left) Detail of the FEM mesh; (Right) Results obtained at two time instances of the numeric simulation



(Left) Compressive pressure pulse generated by and exponential load; (Right) Stretch contour showing shock wave formation in the rod

The predictions of the reduced-order models can help understand the role of material nonlinearity in determining the blast response as well as guide the formation of a complete response picture through detailed three-dimensional simulations.

Contract Performance

A Simulation-Based Framework for Generating Planning Logic for Autonomous Unmanned Vehicles

Currently most unmanned vehicles (UxVs), whether they operate in air, on land, on the sea surface, below the surface, or outer space, are tele-operated via a human or controlled autonomously with hand-coded software. As UxVs become more commonplace and are expected to operate with greater autonomy in more challenging, and sometimes unknown environments, previous methods of generating code by hand become very costly for a number of different reasons. Many man-hours are required to craft robust logic, and there is increased probability that a critical mission will fail because of an unforeseen obstacle. The costs involved in rewriting and improving planning logic code for UxVs operating in the real world can be significant.

ETC has successfully shown that a viable alternative to producing vehicle logic by hand is to have the vehicle learn its own behaviors in a high-fidelity physical simulation environment. In the simulation, missions, obstacles, environmental factors, terrain, sensors, and vehicle parameters can all be modified with much greater speed than in the real physical world. Thus, a vehicle can rapidly be re-trained for a change in mission or engineering specifications. The fact that ETC's simulation environments also allow vehicles and events to be driven by human operators allows experts to verify the accuracy of the simulation, teach behaviors by demonstration, and pit themselves against the machine-controlled vehicle. ETC's environment for Unmanned Sea Surface Vehicles (USSVs) even allows the human operator to wear a head-mounted virtual reality display to further immerse themselves in the simulation.

Integrated with the simulation environment is an architecture for automatically generating software for vehicle operation via various machine learning (ML) techniques and testing it in the environment. A breakthrough in machine learning developed by ETC and the University of Maryland's Simulation-Based System Design Laboratory for these projects involves combining genetic programming with automated identification and patching of failures to automatically synthesize behaviors encapsulated by decision trees. ETC has shown that this modified genetic programming approach generates behaviors that perform as well or better than those coded by a human in such missions as using a USSV to block an intruder from reaching a High Value Target.

Moreover, the machine learning part of the system, running day and night on a cluster of half-a-dozen computers, learned the necessary behaviors and automatically generated the autonomy code in just six days. The human programmer took three weeks to hand-code the behaviors and mission logic to perform the same mission.

ETC has demonstrated its novel approach in two separate projects for the Office of Naval Research (ONR). One is a USSV project that is currently a Phase II effort. It features a simulation environment that integrates realistic ocean conditions from Arete Environment Simulation (AES) software, a real-time hull simplification and boat dynamics engine, simulation logging and replay.

The second is an Unmanned Ground Vehicle (UGV) project that is a Phase I effort. It features a simulation environment based on the Unreal Tournament game engine, NIST's USARSim Framework, and a proprietary C++ controller. The UGV environment integrates terrain that can be based on real elevation models and have adjustable parameters (such as friction), custom-designed sensors for ML, and static and dynamic obstacles. Mission replanning and ML for behaviors such as hill climbing have been demonstrated in this environment.

USSV and UGV simulation environments

Business Development

Empowering Disabled Veterans

The PoWER Center

In 2009, ETC began working with NSWCIH to create a process by which disabled veterans could be hired into meaningful jobs on the naval base. That effort evolved into a new initiative to create a southern Maryland regional learning and education center for veterans with disabilities. A disabled veteran and former Marine became the Program Manager in June 2010 and the initiative was named the Potomac Workforce Education and Recruitment (PoWER) Center. The PoWER Center coordinates support services for disabled veterans and their families, offers guidance and assistance for available education and employment benefits, resume consultation, and skills training to facilitate a seamless transition in to the federal workforce.

The mission of the PoWER Center is to place qualified clients into Maryland jobs that are both challenging and fulfilling, allowing the veteran to utilize their varied skill sets and expertise. The PoWER Center functions under ETC's workforce development charter and also serves to:

- Create an effective process in direct support of our clients by removing obstacles to workforce re-entry and providing training and support services.
- Build community networks with private and public entities creating pathways for permanent job placement for our clients.
- Become part of a national network for disabled veteran job preparation and re-entry into the workforce.
- Develop relationships with the colleges and universities in the community which our clients are most likely to attend. Efforts will be made to ensure veterans who pursue higher education are part of a learning community.

Partnerships

In order to successfully achieve the goals of the PoWER Center, we have developed a network of public/private affiliations consisting of Department of Defense activities and private industry, both of which have shown a commitment to employing our nation's disabled veterans. The Naval Sea Surface Command has set their hiring goal at 365 new hires for the next calendar year, and the PoWER Center is positioned to assist them in attaining their goal.

Status

As of December 2010, the PoWER Center has facilitated over one dozen interviews with several employment offers being considered. Our first successful placement occurred in early December and there are several placements pending within naval commands throughout Maryland.

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Business Development

Energetics Systems Engineering - Weaponization of UxVs

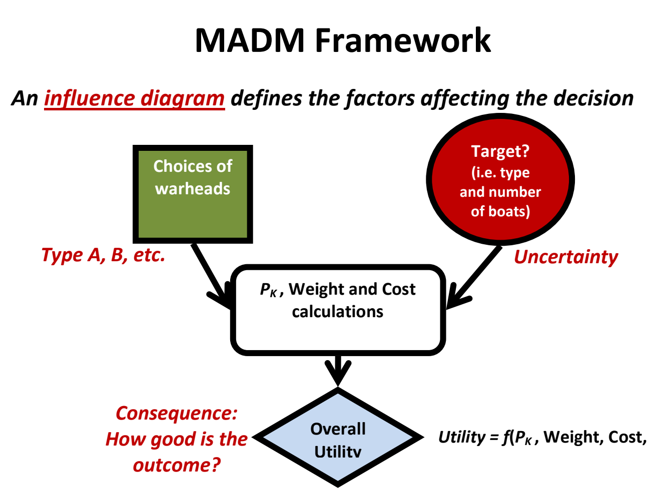
ETC and CECD are supporting NSWCIH in a study of weaponization of UxVs. The Services are beginning to explore the options of arming air, ground and maritime unmanned vehicles beyond the missions currently conducted with the Predators and Reapers. Specific targets may not be identified prior to launch and therefore, multi-effect or multimode weapons are desirable to enhance mission success against a variety of threats. Efforts to date have been focused on integrating existing weapons such as Hellfire missiles onto larger UAV platforms. Lighter more versatile weapons can increase the operational effectiveness of the platforms at all levels. Evolutionary designs are emerging to reduce the weight and cost of the munitions and to arm mid-sized UAVs. Revolutionary designs with advanced energetics and multimode fuzing offer the possibility of target-specific lethality, reduced collateral damage, increased load-outs and more stealthy configurations.

The optimization model being used is a Multi-Attribute Decision Making (MADM) framework. For this exercise, given the 22 warhead/fuzing alternatives, the objectives are to maximize P_k given a hit, and minimize weight and cost. Weighting factors are applied to P_k, weight and cost to reflect their relative importance. Uncertainty and risk arise from the unknown mix of the threat. ETC is in the process of conducting the optimization analysis.

Twenty two potential new warhead options are being evaluated for an optimized load-out on a Fire Scout or other organic UAV to combat an unknown mix of swarming Type I, II and III small boats in the littoral environment. The study is limited to existing and potential new warheads delivered by an existing propulsion system, the APKWS guided version of the 2.75 inch rocket. The warhead variants being considered all weigh about 9 lbs with point detonating and proximity fuzing.

Another case study dealing with the payload selection for a Fire Scout helicopter, which is an Unmanned Air Vehicle (UAV), was analyzed. The conflicting objectives for this problem were minimizing the cost and weight of the helicopter payload, while maximizing the probability of success, when attacked by an unknown number of boats which may be of unknown size.

Future studies may include an advanced, lightweight, multimode weapon for the Tier II UAVs. The Army has recently issued a request for information (RFI) for a weapon system able to engage stationary and moving targets such as light vehicles and dismounted combatants in day and night conditions with low collateral damage when launched from a Shadow UAS. The primary interest is in weapon systems weighing 25 lbs or less.



Multi-Attribute Decision Making framework

Business Development

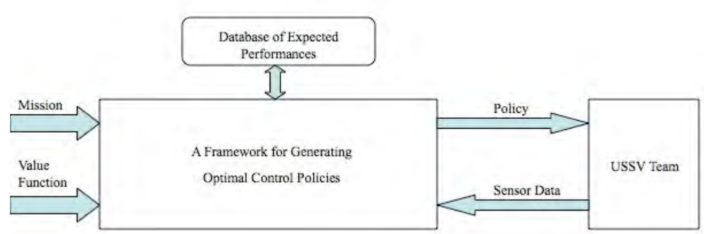
Simulation Based Learning for Optimal Semi-Autonomous Operation of USSV Teams

Complex naval missions often require deployment of teams of Unmanned Sea Surface Vehicles (USSVs) and human operators in unknown environments. These missions may possibly consist of many heterogeneous tasks. An important aspect of the mission planning is the task assignment process for the USSVs. Due to the dynamic nature of the environment, tasks may continuously vary depending upon the state of the environment. Thus, mission planning is not an off-line process but on-line in nature and needs to be performed continually throughout the mission to update the task assignments based on the events in the environment.

Another key decision that needs to be made as a part of the mission planning is to decide whether to operate a particular USSV autonomously or in a tele-operated mode. Depending on the environment encountered during a mission, sections of the workspace may be ideal for autonomous operation and portions of it may require tele-operating the USSVs. Hence, in the near foreseeable future USSV team operations are expected to be semi-autonomous in nature. In order to achieve optimal semi-autonomous operation, several important factors need to be considered. The first important question is how many operators are needed for optimizing the value function for a given mission. The value function for a mission will need to account for both the mission cost and the mission performance. Utilizing a small number of operators may give lead to lower mission cost but also poor mission performance implying poor mission value. On the other hand using too many operators may lead to high cost and only marginally improve the mission performance, thereby again resulting in a low mission value.

Classical optimal control methods such as dynamic programming can be used to optimize the value function if the control designer has good knowledge of the overall system and environment parameters. However, this approach in not viable for controlling the USSV system due to the stochastic nature of the problem and the additional consideration that the number of iterations grow exponentially in the number of states and actions. Hence, learning and stochastic optimization methods have to be deployed to solve the optimal control policy problem for the semi-autonomous USSVs. It is to be noted that to test which policy is optimal, the designer faces several constraints such as the fact that only a single policy can be studied at a particular time on the simulator or the real system. Furthermore, by learning the behavior of one policy, it is not possible to obtain information about other policies if no information is available for the system under consideration. If there is no information about the system, then search methods such as genetic algorithms, simulated annealing, etc. have to be utilized. On the other hand, if structural information is available, then methods such as Markov decision problems, reinforcement learning, and identification and adaptive control can be used to learn the optimal policy.

In this work, we focus on reinforcement learning to obtain the optimal policy for the semi-autonomous USSV systems. Depending on whether the policy space is continuous or discrete, methods such as performance gradient or policy iteration can be adopted. However, assuming that underlying process is Markov, these methods rely on knowing the relative cost in sample paths and the transition probability matrices. These parameters are expected to be largely unknown in the USSV system and hence simulation data will be used to estimate these parameters using reinforcement learning methods. The relative costs and the transition probability matrices, or atleast some of them can be pre-calculated using extensive offline simulations with human operators. Subsequently, it is likely that in the real time scenario, these estimates together with the learning methods will be able to yield the optimal policies for the semi-autonomous USSV system.



A reinforcement learning framework for semi-autonomous control

Business Development

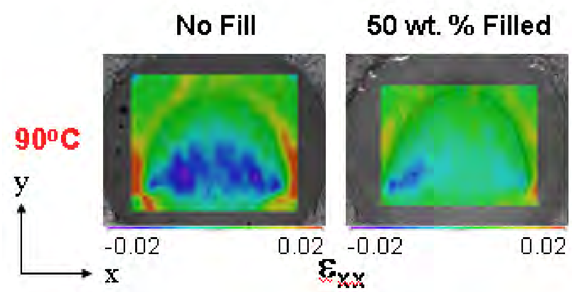
Health Management of Energetics

In-situ mechanical characterization

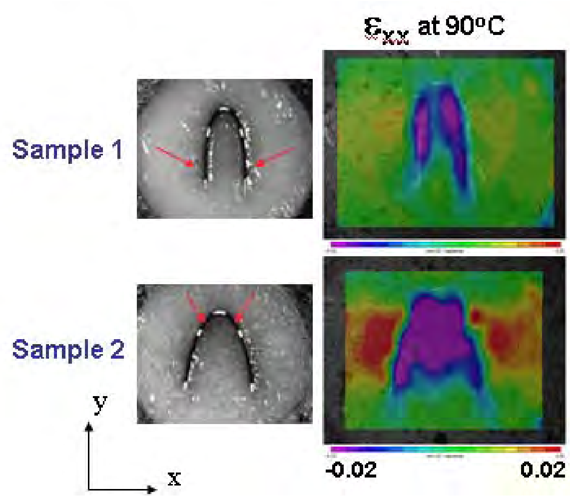
We have developed a technique for characterizing the mechanical behavior of energetic materials using using in-situ loading with embedded SMA actuators and in-situ strain sensing with integrated Fiber Bragg Grating (FBG) optical strain sensors. A thermomechanical treatment and prestrain for the SMA strain sensor has been investigated inorder to control the level of load applied to the energetic material when it is heated. The corresponding loading and response of the energetic material has been characterized using 2-D Digital Image Correlation (DIC), a full-field optical measurement technique. A FBG has then been explored for integration directly with the energetic material and integrated directly to the SMA actuator. The resulting output from the FBG is directly related to the level of loading that has the SMA actuator has been engineered for, and the corresponding deformation response of the energetic material that is related to its mechanical properties. Deterioration in the mechanical properties will result in significantly greater deformation response and output from the FBG. Thus, the output can be directly related to the state of health for the energetic material.

Engineering of SMA actuator

The thermomechanical treatment of the SMA actuator involves shaping of the SMA with a mold, and then holding that shape at a specified temperature and time. The SMA actuator and then be prestrained to a desired level that will be recovered upon heating generating load on the energetic material when the SMA is embedded in it. The temperature at which the loading occurs depends on the composition of the SMA. For these investigations, an SMA ribbon with an actuation temperature of 70°C was chosen. It was shaped into an U-shape geometry during thermomechanical treatment, and then bent after treatment to induce prestrain. The resulting deformation measured with DIC for two different levels of filler can be seen below. The removal of filler is equivalent to deterioration in mechanical properties due to aging, and demonstrates that the SMA actuator can be engineered to a loading level that has sufficient differences in deformation response in the energetic material to be detected by the FBG.



The ability to control the level of loading through prestrain can be seen in the figure below for two different levels of prestrain.



Integration of FBG

To integrate the FBG, two different cases have been investigated. First, the FBG has been attached directly to the energetic material in the region where the maximum strain has been detected by DIC. The second was to attach it directly to the SMA to measure the change in bending. Initial results have indicated that the FBG attached to the SMA can produce a much larger output than attached to the energetic material, making it the more suitable method for increasing measurement accuracy.

Business Development

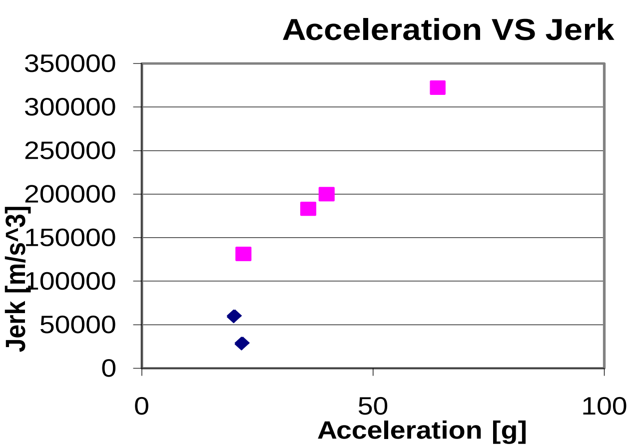
MTBI work in Dynamic Effects Lab – University of Maryland, College Park

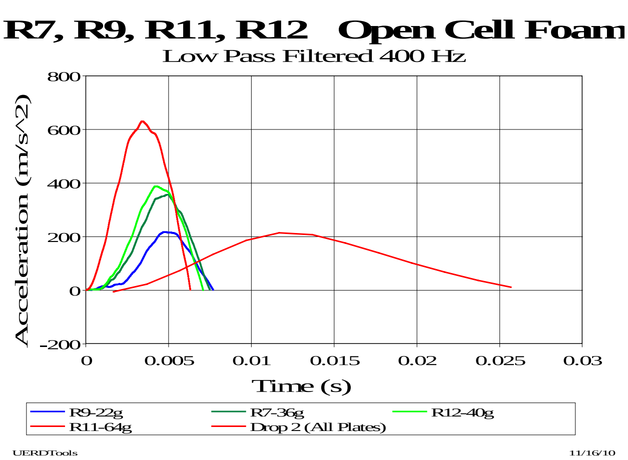
We have been working closely with been working the University of Maryland School of Medicine (UMB) to determine amount of brain injury due to the acceleration of animal subjects in an effort to eventually understand the damage to the human brain subjected to blasts. We have been subjecting animals to given acceleration levels and UMB has been assessing the amount of brain injury. We are working towards a new method of predicting injury. The acceptable method of assessing the amount of injury in automobile crashes has been HIC (Head Injury Criteria) but we have found that this does not work for explosively related accelerations (the loading is applied too quickly).

HIC is really based upon the area under the acceleration time curve and for the very short time durations of accelerations due to explosive loading the HIC values are so small as to not even be in the ballpark of HIC numbers that could cause injuries in car crashes. We have been looking at using jerk (the time rate of change of acceleration (m/s/s/s).

We have tested quite a few animals and UMB has been assessing the amount of brain injury. In the curves below we show results from testing animal subjects. In the first graph we show jerk versus acceleration level. The graph shows acceleration levels can be as high a 20gs from a fall (points shown in blue) of only a few inches – yet cause no brain injury. On the other hand an acceleration of 20 gs from an explosively caused movement is also in the range of 20 gs and does cause brain injury. In the second curve we show acceleration versus time data from a drop of 9 inches (the long low curve) as well as curves from various blasting tests. Notice that the jerk (the slope of the acceleration time curve) of the drop test is only on the order of 50,000 m/s/s/s while jerk on the order of 300,000 can be caused by explosive loading.

We hope to show that jerk is a good indicator of brain injury where acceleration alone is not.





Business Development

Properties of Brain Tissue

Brain tissue is composed of water and solid phases. This internal water is in addition to the water in the cerebrospinal fluid surrounding the brain. The material properties and the model chosen must account for the water content. The different types of brain tissue include the homogeneous grey matter, the fibered white matter, blood vessels, and connecting material. Initially, the behavior of grey and white matter separately and also at their interface are studied to produce a nonlinear viscoelastic (time-dependent) model.

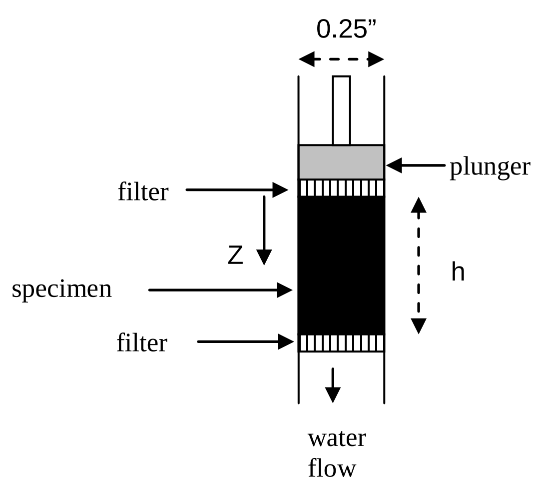
The internal water content of the tissue strongly affects the mechanical response. The moisture content of a rat brain was determined by freezing it and then creating a vacuum in the chamber so that all the water sublimates from the tissue. The moisture content was measured as 81% by weight, proving that the flow of water through the tissue pores cannot be neglected in the mechanical response.

The three key loads on the brain under a pressure impulse are compression, shear and tension. The compressive behavior controls the flow of water in the tissue. The flow depends on the permeability coefficient, which in turn depends on the compressive deformation that tends to close pores. No one has yet investigated the role that a sudden water flow within the tissue in response to a pressure impulse might have on TBI. The shearing is believed to be a major cause of cell rupture and connective tissue rupture in the primary impulse event in TBI. Secondary effects due to biochemistry are studied by others.

Confined compression tests of a material compressed in a cylinder to prevent lateral deformation have been conducted on a specially designed and built fixture in which the cylinder has diameter 0.25 inch. Loads less than 125 grams occur up to the 20% strain at which damage is believed to begin. Because the load is so small, friction must be nearly eliminated in the fixture. A new differential equation analysis describes the deformation due to unsteady fluid flow in the tissue. A new, complex computer program extracts the permeability and other unsteady parameters from the data using several numerical methods in combination.

A shear fixture has been designed to apply a lateral shear, rather than a twist shear, that can shear thin rectangular specimens as small of 0.5 mm on a side. The lateral type of shear is expected in the brain tissue during the primary TBI impulse. The small size is necessary for specimens of either purely white or purely grey rat brain tissue.

To reduce the number of frequencies at which tests must performed and so to simplify the experimental effort, the frequencies occurring in a typical blast pressure wave have been identified by a harmonic wavelet analysis that shows not only the important frequencies but the time at which they contribute to the impulse signal. Each wavelet has a peak at its center time and then drops rapidly to zero with a rate of decay inversely proportional to time. This decomposition contrasts to a Fourier frequency analysis that is only valid for a stationary wave over all time.



Confined compression apparatus

Business Development

Energetics Informatics

ETC/CECD/NSWCIH have begun the development of an information system and *knowledge base* to support a wide range of energetics research and development needs. The ultimate goal is to have a knowledge base that contains or has access to existing raw data and processed information – and will be improved and supplemented by expert knowledge from energetics subject matter experts.

Energetics Informatics Data Warehouse (EIDW) utilizes a state-of-the-art associative database management system to assimilate, organize, relate, and present a broad range of energetics data from a variety of sources. A web-based front-end to the system has been developed to allow end users to view and mine the data using an interface customized to their level of access and to their preferred point of entry.

The novel associative data model approach adopted by the team has a number of benefits compared to a traditional relational data model, including both high speed traversal of large data collections and a higher level of structural flexibility that allows for both rapid database development and the freedom to quickly create new or modify existing relationships between data elements as needed. This approach centers each data element in its own universe, and allows the end user to discover relationships within their data that may not have been apparent using other systems.

A prototype system is being developed, which contains key Navy energetics documents and databases related to explosives, pyrotechnics, and propellants. To assist in characterizing the state of energetics in other countries, abstracts from more than 600 papers and journal articles from around the world were assimilated into the system. Some 20 databases and thousands of pages of other relevant documentation have been incorporated as well. Areas of focus for current and near term data collection efforts include:

- Identification of sources of energetic data, both electronic and paper-based
- Collection of open source energetics data based on keywords and other parameters (e.g., country of origin)
- Documentation of user needs and priority of requirements for new capability development
- Identification of algorithms, models, and other tools needed to perform customized queries and analysis.

The overall objective of this effort is to deliver a production level information management and analysis system to support the varied needs of organizations related to energetics materials and technology. Based on user feedback, initial areas of interest include:

- *Taxonomy of Energetics*
- *Foreign Documentation*
- *Expert Knowledge-Related Data of Interest*

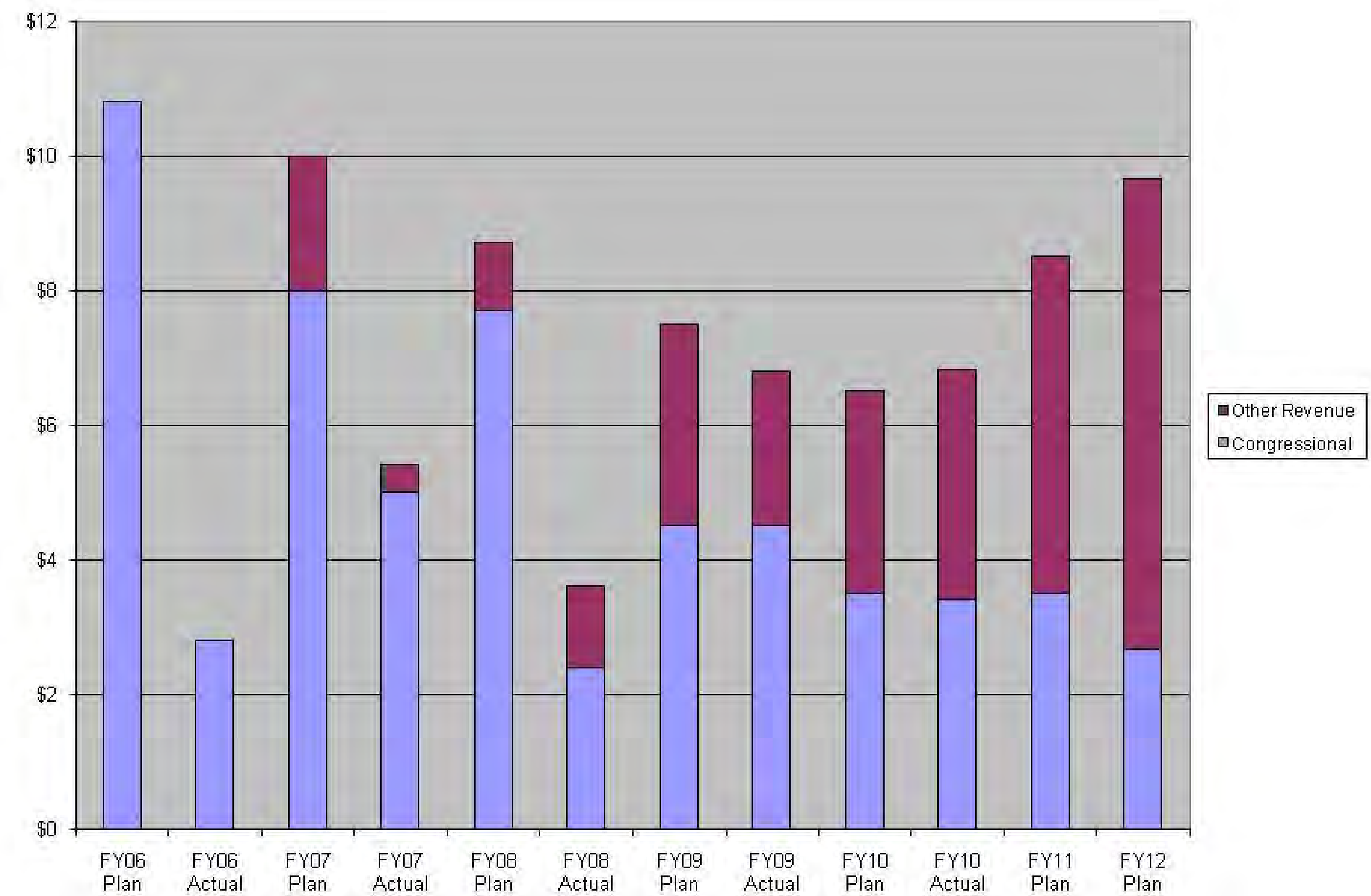
A "tag cloud" created with energetics taxonomy data from NSWCIH representing the frequency of terms appearing in data elements in the EIDW

Revenues

Our main goal for technical and workforce development-related efforts is to execute a program that enhances our pre-eminence in energetics and related technologies. Specific objectives are: 1. To grow and expand core CECD research thrusts; 2. To initiate ETC technology development projects that result in additional revenue coming into the ETC; and 3. To build a long-term technical foundation that is recognized as an important part of the national security infrastructure.

CECD/ETC and NSWCIH leadership continue to have strategic planning discussions to ascertain how best to utilize funding for the long-term benefit of the Energetics community, and the leadership role envisioned for NSWCIH and its CECD/ETC partner. These discussions will continue to shape our business plans in the future.

In 2010, we continued to build a strong revenues stream through projects funded by NSWCIH, ONR, NSWCDL, and DoD. Revenues received from non-congressional sources exceeded those from congressional sources for the first time.



CECD/ETC revenues

Energetics Research, Education, and National Security

The national security benefits of the Southern Maryland Initiative fall into a variety of categories. The Initiative enables the country to maintain an ordnance technology edge; heighten national security; improve warfighting effectiveness; produce commercial applications; enhance our national position for technological international competitiveness; provide a pool of talent for industry; and create a knowledge feed stream for a broad range of related high technology areas.

The advancements in the fundamental sciences of explosives, propellants, and electronics will naturally provide spin-off applications that will become benign civilian products in the international marketplace. Concurrently, the initiative will provide a pool of talent for industry and create a knowledge feed stream for a broad range of related high technology areas. Both of these things are inherent elements of improved national security. As the ordnance industry ages, it, too, will need to rejuvenate its workforce with appropriate talent. The initiative will provide a comprehensive function to create the solution to this need. Not all individuals trained and experienced through the Initiative are expected to remain in Southern Maryland. It is a natural event in our society that individuals seek to better themselves, and the Center will provide a ready pool of talent to be recruited at the time that industry needs them. This, combined with the continual feed stream of ordnance knowledge produced in the Center, will strengthen and enhance our national security.

The CECD/ETC Enterprise clearly provides significant and substantial benefits for our national security.

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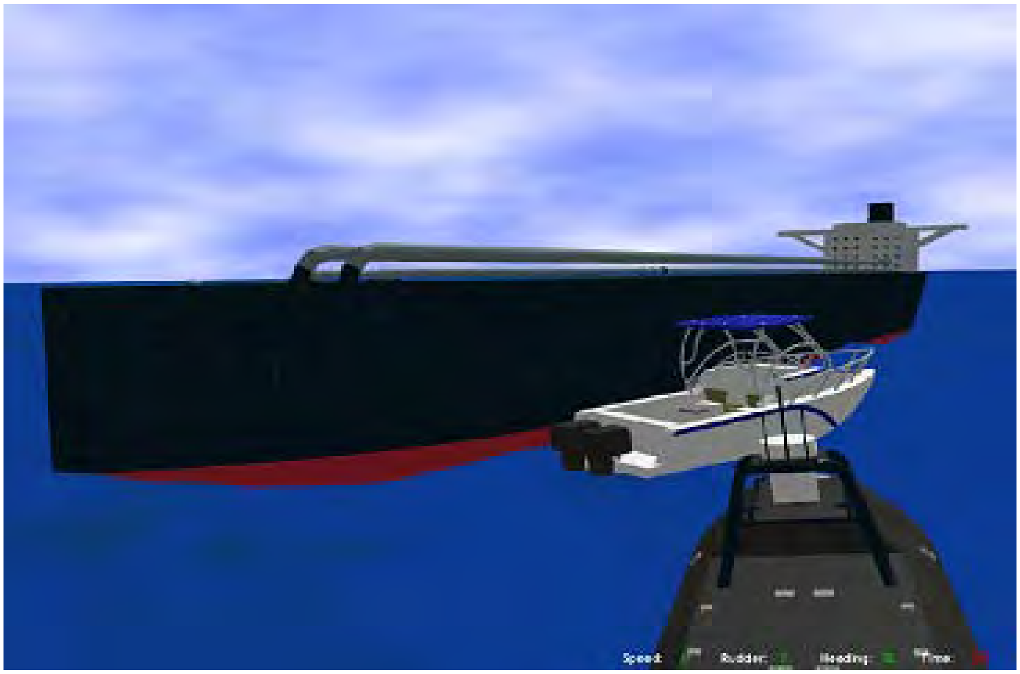
The CECD/ETC Enterprise Growing Science & Technology in Southern Maryland



Simulation in Virtual Reality

A Catalyst for Science and Technology in Southern Maryland