Office of the Secretary of Defense (OSD)
Assistant Secretary of Defense (Research & Engineering)
13.3 Small Business Innovation Research (SBIR)
Proposal Submission Instructions

Introduction

The Assistant Secretary of Defense (Research & Engineering) SBIR Program is sponsoring topics in the following technology focus areas: Autonomous Technology; Integrated Computational Materials Engineering; Operational Energy and Power; Data Research and Analysis; and Unmanned Aerial Systems Propulsion Durability and Technology.

The Army, Navy, Air Force, and the Defense Threat Reduction Agency are participating in the OSD SBIR Program on this solicitation. The Service laboratories act as OSD's Agent in the management and execution of the contracts with small businesses.

In order to participate in the OSD SBIR Program, all potential proposers should register on the DoD SBIR Web site at http://www.dodsbir.net/submission as soon as possible. Follow the instructions for electronic submittal of proposals. It is required that all proposers submit their proposal electronically through the DoD SBIR/STTR Proposal Submission Web site at http://www.dodsbir.net/submission. If you experience problems submitting your proposal, call the SBIR/STTR Help Desk (toll free) at: 1-866-724-7457.

Refer to Section 4.15 of the DoD Program Solicitation for the process of submitting questions on SBIR and Solicitation Topics. During the Pre-release period, proposers have an opportunity to contact topic authors by telephone or e-mail to ask technical questions about specific solicitation topics, however, proposal evaluation is conducted only on the written proposal. Contact during the Pre-release period is considered informal, and will not be factored into the selection for award of contracts. Contact with the topic authors by telephone or e-mail after the Pre-release period is prohibited. To obtain answers to technical questions during the formal Solicitation period, please visit http://www.dodsbir.net/sitis. Refer to the Program Solicitation for the exact dates.

OSD WILL NOT accept any proposals that are not submitted through the on-line submission site. The submission site does not limit the overall file size for each electronic proposal; however, there is a **20-page limit**. File uploads may take a great deal of time depending on your file size and your internet server connection speed. If you wish to upload a very large file, it is highly recommended that you submit your proposal prior to the deadline submittal date, as the last day is heavily trafficked. You are responsible for performing a virus check on each technical volume file to be uploaded electronically. The detection of a virus on any submission may be cause for the rejection of the proposal.

Firms with strong research and development capabilities in science or engineering in any of the topic areas described in this section and with the ability to commercialize the results are encouraged to participate. Subject to availability of funds, the ASD(R&E) SBIR Program will support high quality research and development proposals of innovative concepts to solve the listed defense-related scientific or engineering problems, especially those concepts that also have high potential for commercialization in the private sector. Objectives of the ASD(R&E) SBIR Program include stimulating technological innovation, strengthening the role of small business in meeting DoD research and development needs, fostering and encouraging participation by minority and disadvantaged persons in technological innovation, and increasing the commercial application of DoD-supported research and development results. The guidelines presented in the solicitation incorporate and exploit the flexibility of the SBA Policy Directive to encourage proposals based on scientific and technical approaches most likely to yield results important to DoD and the private sector.

Proposal Submission

Refer to Section 5.0 of the DoD Program Solicitation for program requirements and proposal submission. Proposals shall be submitted in response to a specific topic identified in the following topic description sections. The topics listed are the only topics for which proposals will be accepted. Scientific and technical information assistance may be requested by using the SBIR/STTR Interactive Technical Information System (SITIS).

Proposer Eligibility and Limitations

Each proposer must qualify as a small business for research or research and development purposes and certify to this on the Cover Sheet of the proposal. In addition, a minimum of two-thirds of the research and/or analytical work in Phase I must be carried out by the proposing firm. For Phase II, a minimum of one-half (50%) of the research and/or analytical work must be performed by the proposing firm. The percentage of work is usually measured by both direct and indirect costs, although proposers planning to subcontract a significant fraction of their work should verify how it will be measured with their DoD contracting officer during contract negotiations. For both Phase I and II, the primary employment of the principal investigator must be with the small business firm at the time of the award and during the conduct of the proposed effort. Primary employment means that more than one-half of the principal investigator's time is spent with the small business. Primary employment with a small business concern precludes full-time employment at another organization. For both Phase I and Phase II, all research or research and development work must be performed by the small business concern and its subcontractors in the United States. Deviations from the requirements in this paragraph must be approved in writing by the contracting officer (during contract negotiations).

Joint ventures and limited partnerships are permitted, provided that the entity created qualifies as a small business in accordance with the Small Business Act, 15 U.S.C. § 631.

Definition of a Small Business

A small business concern is one that, at the time of award of Phase I and Phase II, meets all of the criteria established by the Small Business Administration which are published in 13 C.F.R § 121.701-705, repeated here for clarity. A small business concern is one that, at the time of award of Phase I and Phase II, meets all of the following criteria:

a. Is independently owned and operated, is not dominant in the field of operation in which it is proposing, has a place of business in the United States and operates primarily within the United States or makes a significant contribution to the US economy, and is organized for profit.

b. Is (a) at least 51% owned and controlled by one or more individuals who are citizens of, or permanent resident aliens in, the United States, or (b) it must be a for-profit business concern that is at least 51% owned and controlled by another for-profit business concern that is at least 51% owned and controlled by one or more individuals who are citizens of, or permanent resident aliens in, the United States.

c. Has, including its affiliates, an average number of employees for the preceding 12 months not exceeding 500, and meets the other regulatory requirements found in 13 CFR Part 121. Business concerns are generally considered to be affiliates of one another when either directly or indirectly, (a) one concern controls or has the power to control the other; or (b) a third-party/parties controls or has the power to control both.

Control can be exercised through common ownership, common management, and contractual relationships. The term "affiliates" is defined in greater detail in 13 CFR 121.103. The term "number of employees" is defined in 13 CFR 121.106.

A business concern may be in the form of an individual proprietorship, partnership, limited liability company, corporation, joint venture, association, trust, or cooperative. Further information may be obtained at http://sba.gov/size or by contacting the Small Business Administration's Government Contracting Area Office or Office of Size Standards.

Description of the OSD SBIR Three Phase Program

Phase I is to determine, insofar as possible, the scientific or technical merit and feasibility of ideas submitted under the SBIR Program and will typically be one half-person year effort over a period not to exceed six months, with a dollar value up to $150,000. OSD plans to fund three Phase I contracts, on average, and down-select to one Phase II contract per topic. This is assuming that the proposals are sufficient in quality to fund this many. Proposals are evaluated using the Phase I evaluation criteria, in accordance with Section 6.0 of the DoD Program Solicitation. Proposals should concentrate on research and development which will significantly contribute to proving the scientific and technical feasibility of the proposed effort, the successful completion of which is a prerequisite for further DoD support in Phase II. The measure of Phase I success includes technical performance toward the topic objectives and evaluations of the extent to which Phase II results would have the potential to yield a product or process of continuing importance to DoD and the private sector.

Subsequent Phase II awards will be made to firms on the basis of results from the Phase I effort and the scientific and technical merit of the Phase II proposal in addressing the goals and objectives described in the topic. Phase II awards will typically cover two to five person-years of effort over a period generally not to exceed 24 months (subject to negotiation), with a dollar value up to $1,000,000. Phase II is the principal research and development effort and is expected to produce a well defined deliverable prototype or process. A more comprehensive proposal will be required for Phase II. In order for a small business to be considered for a Phase II award, the firm must be a recipient of a Phase I award under that topic.

All Phase I awardees will be allowed to submit a Phase II proposal for evaluation and selection. The details on the due date, content, and submission requirements of the Phase II proposal will be provided by the awarding technical point of contact and/or the contracting officer by subsequent notification. All SBIR/STTR Phase II awards made on topics from solicitations prior to FY2013 will be conducted in accordance with the procedures specified in those solicitations (this means by invitation only).

Under Phase III, the DoD may award non-SBIR funded follow-on contracts for products or processes, which meet the Component mission needs. This solicitation is designed, in part, to encourage the conversion of federally sponsored research and development innovation into private sector applications. The small business is expected to use non-federal capital to pursue private sector applications of the research and development.

DoD is not obligated to make any awards under Phase I, II, or III. For specifics regarding the evaluation and award of Phase I or II contracts, please read the front section of this solicitation very carefully. Phase II proposals will be reviewed for overall merit based upon the criteria in Section 4.3 of this solicitation.

This solicitation is for Phase I proposals only. Any proposal submitted under prior SBIR solicitations will not be considered under this solicitation; however, offerors who were not awarded a contract in response to a particular topic under prior SBIR solicitations are free to update or modify and submit the same or modified proposal if it is responsive to any of the topics listed in this section.

Phase II Plus Program

The OSD SBIR Program has a Phase II Plus Program, which provides matching SBIR funds to expand an existing Phase II contract that attracts investment funds from a DoD acquisition program, a non-SBIR/non-STTR government program or Private sector investments. Phase II Plus allows for an existing Phase II OSD SBIR contract to be extended for up to one year per Phase II Plus application, to perform additional research and development. Phase II Plus matching funds will be provided on a one-for-one basis up to a maximum $500,000 of SBIR funds. All Phase II Plus awards are subject to acceptance, review, and selection of candidate projects, are subject to availability of funding, and successful negotiation and award of a Phase II Plus contract modification. The funds provided by the DoD acquisition program or a non-SBIR/non-STTR government program must be obligated on the OSD Phase II contract as a modification just prior to or concurrent with the OSD SBIR funds. Private sector funds must be deemed an “outside investor” which may include such entities as another company, or an investor. It does not include the owners or family members, or affiliates of the small business (13 CFR 121.103).

Follow-On Funding

In addition to supporting scientific and engineering research and development, another important goal of the program is conversion of DoD-supported research and development into commercial (both Defense and Private Sector) products. Proposers are encouraged to obtain a contingent commitment for follow-on funding prior to Phase II where it is felt that the research and development has commercialization potential in either a Defense system or the private sector. Proposers who feel that their research and development has the potential to meet Defense system objectives or private sector market needs are encouraged to obtain either non-SBIR DoD follow-on funding or non-federal follow-on funding, for Phase III to pursue commercialization development. The commitment should be obtained during the course of Phase I performance, or early in the Phase II performance. This commitment may be contingent upon the DoD supported development meeting some specific technical objectives in Phase II which if met, would justify funding to pursue further development for commercial (either Defense related or private sector) purposes in Phase III. The recipient will be permitted to obtain commercial rights to any invention made in either Phase I or Phase II, subject to the patent policies stated elsewhere in this solicitation and awarded contract.

The following pages contain a summary of the technology focus areas, followed by the topics within each focus area.

AUTONOMOUS TECHNOLOGY THEME

The role of unmanned systems in Department of Defense operations has grown exponentially over the last several years. Unmanned systems enable 24/7 persistence, advanced operational capabilities, and impressive response times. Although these systems do not have humans onboard, they do require extensive human-based command and control. The term "autonomous technology" is often used to describe a range of machines and/or systems--including unmanned aircraft, space vehicles, surface and underwater vehicles, ground vehicles, weapons, information technology (IT), and the many sub-systems within each. Autonomous technologies involve software-based tools for machine-based decision making. These tools are frequently developed to convert raw data into actionable information. Although significant progress has been made to develop and field technologies with different levels of autonomous functionality, there are significant technical capability gaps, particularly when executing dynamic missions in dynamic environments.

Autonomous systems will play a critical role in future US military operations in air, land, sea, space, and cyberspace. Advancements in the following four areas are critical to developing effective autonomous technology for the warfighter:

1. Human/Autonomous Systems Interaction and Collaboration:

- Integration of Autonomy, Artificial Intelligence and Human Cognitive, or Other Human Models
- Optimized Trust and Transparency in Automation and Autonomy Automation/Transparency
- Advanced Interfaces to Maximize Shared Perception between Human(s) and Agent(s)
- Advanced Control System Interfaces with Human Factors Engineering Focus

2. Scalable Teaming of Multiple Autonomous Systems:

- Shared Problem Solving/Reasoning/Perception between Heterogeneous Agents
- System Health Management/Attrition Management between Heterogeneous Agents
- Secure Communication between Heterogeneous Agents

3. Machine Reasoning, Perception, and Intelligence:

- Sensor Data-Driven Analytics and Data Decision Models
- Advanced Algorithms to Enable Robust Operations in unstructured environments
- Contingency-based Control Strategies and Integrated Contextual Decision Making
- Adaptive Guidance and Control integration with higher level reasoning, decision-making, learning.
- Domain Management (e.g., Airspace, Waterspace, Surface Traffic) and Mission Control

4. Test, Evaluation, Validation, and Verification:

- Virtual and Constructive Test Beds for Human-Agent Teaming
- Simulation Test Beds for Operation in Complex, Contested Environments

The following topics are in this theme area:
OSD13-HS1
OSD13-HS2
OSD13-HS3
OSD13-HS4
OSD13-HS5

INTEGRATED COMPUTATIONAL MATERIALS ENGINEERING THEME

The Office of the Secretary of Defense is interested in innovative, collaborative research associated with the broad area of integrated computational materials engineering.[1] The Department of Defense (DoD) views computational materials approaches to be a means to accelerate the development and insertion of new or enhanced materials and materials systems for desired defense capabilities. It is doing this through investments in basic and applied research, in addressing specific foundational engineering problems (FEPs) to solve nearer-term challenges, and in pervasive infrastructure and underlying knowledge to enable accelerated discovery, development, performance prediction and certification of materials and systems. Advances in computational materials modeling and simulation are necessary, but not sufficient to effect the change needed. New tools must be developed to characterize the critical features that define material performance not with traditional qualitative descriptors, but rather with quantitative data sets and models readily exploitable by emerging computational techniques.

Specifically in acquisition and sustainment, research is being planned in (a) accelerating discovery, development, performance prediction and certification of materials and systems; (b) providing predictive tools for more affordable and efficient structural health management of military assets, and (c) developing a durability and damage tolerance equivalent for polymer-matrix composites and similar nonmetallic systems and component/material damage characterization, which are needed to advance fleet integrity programs and meet operational commitments. Additional effort is needed to transition the required knowledge bases and computational codes from the fundamental research arena to those who will be manufacturing the products, including original equipment manufacturers and second- and third-tier suppliers.

The following topics are in this theme area:
OSD13-C01
OSD13-C02
OSD13-C03
OSD13-C04
OSD13-C05

OPERATIONAL ENERGY AND POWER THEME

Background/Challenge: Technological advances in electric power generation, distribution and use are enabling transformational military capabilities. Advanced power generating technologies enable significant improvements in platform flexibility, survivability, lethality and effectiveness. The Army's transformation challenge is to develop a smaller, lighter, and faster force, utilizing hybrid electric drive, electric armament and protection, and a reduced logistical footprint. The Navy is developing future ship concepts that integrate electric power into a next-generation architecture which enables directed energy weapons, electromagnetic launchers and recovery, new sensors, as well as supporting significant fuel, maintenance, and manning reductions. The Air Force needs electric power to replace complex mechanical, hydraulic and pneumatic subsystems, and also enable advanced electric armament systems. Improved power sources will support the individual soldier by permitting longer duration missions and reduced weight borne by the soldier.

Research Goals/Focus Areas: The DoD Operational Energy Implementation Plan, March 2012, asked that the Assistant Secretary of Defense for Research and Engineering (ASD(R&E)) identify investment gaps in the Department's science and technology (S&T) portfolio necessary to reduce power demand, improve system efficiency, and expand supply alternatives, as articulated in the DoD Operational Energy Strategy. In this assessment, the following areas were identified as Gaps/Priority areas.

(1) High Efficiency Energy Conversion
(2) Energy Integrated Design & Simulation
(3) High Efficiency Propulsion
(4) Environmental Control Systems
(5) Flexible & Adaptive Power Distribution/

The following topics are in this theme area:
OSD13-EP1
OSD13-EP2
OSD13-EP3
OSD13-EP4
OSD13-EP5

DATA RESEARCH AND ANALYSIS

I. Background/Challenge

The Department of Defense (DoD) continues to have a Science and Technology (S&T) Priority Area Data to Decisions (D2D) which seeks science and applications to insure that real data drives decision-making within mission time constraints and human capital limits. Decisions are impacted by available data from the tactical edge all the way up through strategic level information and knowledge. From an analytical perspective, increasing sensor volume, velocity, and variety augmented by the availability and relevance of open source information raise the expectations and standards for high quality analysis and decision making. The need to discover, identify, and characterize diverse problem spaces defined by complex, incomplete, imprecise, dynamic and potentially contradictory large data sets has become a critical issue in military decision-making as it is beyond the abilities of humans to read and assimilate such large data sets and create comprehensive analytic products that leverage them. The drive to use increasing amounts of information across every DoD domain and mission area in a way that encourages deep and meaningful interactions with data that impacts decisions requires more efficient and effective functions.

II. Research Goals/Focus Areas:

Data challenges are common across the DoD such as data discovery, data synchronization, data analysis, and data quality. These challenges increase the time and manpower required to operate effectively. Projects will seek to investigate new techniques for data discovery through multiple modes of interaction with data as well as leverage advanced analytics currently employed in disparate mission areas with similar conceptual challenges. A topic will seek to demonstrate effective use in a particular mission or domain with an understanding of the supporting data system, analytical tools, time constraints, and human capital required to achieve a capability. Projects within the topic should not require excessive data preparation and information management by an expanding number of highly skilled analysts or back office IT experts for support. Topics will seek simpler methods of user-composed, tailored processes and tools to demonstrate novel approaches, repurposing of methods to new areas, and reuse of data.

Technical areas of focus for Data Research and Analysis SBIR topics are advanced visualization and novel interaction methods for discovery, characterization, analysis, and use. Advanced visualization efforts are expected to demonstrate a workstation-free and untethered computational capability with effective large-scale analytics. Projects will seek to provide evidence of efficiency gains over current approaches with respect to time or human capital requirements.

The following topics are in this theme area:
OSD13-LD1
OSD13-LD2
OSD13-LD3

UAS PROPULSION DURABILITY & TECHNOLOGY THEME

Background/Challenge

Unmanned Aerial Systems (UAS) are a critical part of our National Security but experience a large number of engine related losses. The UAS number in the hundreds and when small hand held UAS are considered, they number in the thousands. However, unlike the manned aircraft, the UAS propulsion systems lack durability due to engines not being designed for the flight duty cycle (operating at near full power for the flight duration) encountered. Two prominent systems which our country has are the USAF's Predator and US Army's Shadow-200 and both are powered by spark ignited gasoline engines. However, these engines are very expensive and have very limited life cycles. The Predator's engine life is 1080 hours with overhauls done at 360 hours and the Shadow's engine life is 250 hours with overhauls done at 120 hours. Every year we lose a consistent number of UAS due to some type of engine failure, Class A mishaps. There are a number of smaller UAS platforms that have engines in the 10 HP range that also suffer from poor durability. If durability for these systems can be increased so that a consistent Time-Between-Overhaul (TBO) can be established than the confidence of the propulsion system reaching full life would increase. This SBIR/STTR theme is in line with the OSD critical research area of Autonomy (science and technology to achieve autonomous systems that reliably and safely accomplish complex tasks, in all environments) aimed at reducing durability failure issues for UAS engines from 10 HP to 200 HP.

The technical challenge is to increase UAV propulsion durability in a cost effective manner. Cost Effective Durability with can be defined in dollars per hour (the cost of the engine, including rebuilds over the life of the engine in hours); hence a durability rate.

The following topics are in this theme area:
OSD13-PR1
OSD13-PR2
OSD13-PR3
OSD13-PR4
OSD13-PR5

OSD SBIR 13.3 Topic Index

OSD SBIR 13.3 Topic Descriptions

OSD13-C01 TITLE: Integrated Computational Materials Engineering in Multiphysics Software

TECHNOLOGY AREAS: Materials/Processes

OBJECTIVE: The objective of this research is to demonstrate a spatially-dependent calculation of detailed microstructural evolution (e.g., grain structure, texture, precipitation kinetics, phase transformations, etc.) in the modeling of processing of a structural material ultimately providing or enhancing commercial multiphysics software (e.g., general multiphysics or specialized for welding, forging, molding, casting, extrusion, thermal spraying, powder processing, etc.). This project supports the goals of the Materials Genome Initiative (MGI) in the area of Integrated Computational Materials Engineering (ICME).

DESCRIPTION: During materials processing operations, the microstructure, physical properties, and mechanical properties of a material can change significantly, both globally and in localized regions of complex shapes. These changes can affect the behavior of the material during the processing operation, as well as the final properties and performance in service. Several simple examples include the evolution of spatially-varying microstructure and texture during the closed-die forging of titanium alloys and nickel-base superalloys which often involve complex strain, strain rate, and temperature histories. Despite such complexity, most research groups persist in using oversimplified phenomenological material models such as engineering stress-strain relations, Avrami-based recrystallization relations, and other related approaches. Though the bases for these models revolve around some physical concepts (e.g., nucleation and growth phenomena), the models themselves are often ad hoc or limited to a very specific processing regime over which measurements are available. The parameters that designers and analysts use to represent materials behavior are convenient for databases, and the models calculate rapidly for analysis, but predictions often match measured behavior only approximately – and sometimes worse.

A long-term vision for Integrated Computational Materials Engineering and the Materials Genome Initiative involves providing complete spatial descriptions of the evolution of microstructure, texture, and defects during materials processing operations and resulting service properties. This would enable the design of both the material and process for end-state properties tailored for a particular application. Current multi-physics software packages generally provide only rudimentary single-value, or temperature-dependent, material properties. Although single-parameter state variables provide useful insight for such parameters as “damage”, they are not sufficient to describe completely (or even partially) the state of the material. Some codes provide the ability to estimate microstructural information, such as grain size or fraction of transformed/recrystallized phase developed during or following deformation based on phenomenological relations. In addition, mesoscale simulations such as those based on Monte-Carlo, cellular automaton, and phase-field approaches may provide spatially resolved information, but often such codes need input from global FEM type process-simulation runs. Such de-coupled methods (involving post-processing-FEM predicted field variables as input to mesoscale simulations of microstructure) are computationally simple, and provide simple system models for optimization, but may not totally account for real material non-linearity and the path dependence of microstructure evolution during multi-step processes. Furthermore, in many instances, only specialized university-developed (non-commercial) codes provide the ability to calculate microstructure and property evolution in complex solidification, deformation, and heat treatment operations.

PHASE I: The successful phase I research will present a generic structure for complex data comprising of microstructure and properties. The investigators will provide a detailed plan to integrate this data structure, and the evolution of this data structure, within the existing confines of a thermomechanical-processing simulation code, that is suitable for modeling the multi-step manufacture of a metal with arbitrary boundary conditions such as finite element analysis. It is important to note that this data structure must be sufficiently flexible to allow modeling with a number of different microstructural and textural features/components.

PHASE II: In the phase II effort, the investigators will carry out the plan devised in phase I and incorporate the materials microstructure data structure into their code, and demonstrate performance for pertinent microstructural features (or feature such as grain size, grain, shape, precipitate size/volume fraction) in a multi-step manufacturing process. They shall also demonstrate that they can expand the system on demand to accommodate a large number of features/states for a material, and associated local constitutive behaviors. Note that many interesting behaviors will include non-uniform deformation and large changes in local strain rate or temperature during processing. The code must accommodate this in a reasonable manner for the analyst/designer to understand and utilize. This effort must also include verification and validation of the simulation code and material models, quantification of uncertainty, transport of data between process and service-behavior simulations, and methods of describing the detailed pedigree and sharing of all material and process data for other computer-base applications.

PHASE III: The design of components requires the ability to determine accurately the structure and properties that evolve during primary processing and manufacturing operations. This toolset will allow the metals suppliers to better simulate their processing operations, which will enable superior design of their processing and manufacturing operations. This is of considerable interest to the aerospace and automotive industries. This will speed the design process and result in systems optimized for superior reliability.

PRIVATE SECTOR COMMERCIAL POTENTIAL/DUAL-USE APPLICATIONS: The processing of materials using non-uniform applied conditions is routine in all of processing and manufacturing. The local behavior of the material becomes extremely important to the response of the material, and the overall success in the processing operation. We anticipate that the specific code developed in this project will find immediate use in the processing industry for critical components in all sectors of the economy. We further anticipate that the approaches and methods developed in this project will find their way into other codes for process modeling and simulation. Although the methods and approaches may be too expensive computationally for proof-of-concept-level designs, we expect these approaches to become routine for the integrated detail design of materials, processes, manufacturing operations, and components.

REFERENCES:
1. ASM Handbook, Vol. 22A: Fundamentals of Modeling for Metals Processing, ASM International, Materials Park, OH, 2009.

2. ASM Handbook, Vol. 22B: Metals Process Simulation, ASM International, Materials Park, OH, 2010.

3. S. L. Semiatin, N. Frey, S. M. El-Soudani, J. D. Bryant, "Flow softening and microstructure evolution during hot working of wrought near-gamma titanium aluminides", Metallurgical Transactions A23 (1992) 1719-1735.

4. Zhe-jun WANG, Hong-fu QIANG, Xue-ren WANG, Guang WANG, "Constitutive model for a new kind of metastable â titanium alloy during hot deformation", Trans. Nonferrous Met. Soc. China 22(2012) 634&641.

KEYWORDS: Materials Genome Initiative, MGI; Integrated Computational Science and Engineering, ICME; Process Modeling and Simulation; Materials design

OSD13-C02 TITLE: A Semantic Technology for Materials Design and Development

TECHNOLOGY AREAS: Information Systems, Materials/Processes

OBJECTIVE: Develop and demonstrate the foundational elements required to create a semantic technology for materials design and development.

DESCRIPTION: Several foundational elements required to achieve Sir Tim Berners-Lee's vision for a semantic web are in place and available to the materials community. The semantic web, sometimes referred to as the web-of-data, focuses on ontologies as well as the linking data for machine-to-machine data interchange (implemented via RDF and OWL). Linkage between multiple datasets, files and their respective metadata can be established in an ad hoc fashion without having to adhere to specific database table structures.

Linked data without context is of limited value. A semantic web for materials requires common vocabularies. An example of a common vocabulary is the Dublin Core (DC) ontology, a set of universally accepted metadata used to describe a resource (e.g. document). The development and publishing of vocabulary using RDFS/OWL is one of the initial steps required to link relevant materials information across disparate (federated) sources. The development of common vocabularies could be jump-started by businesses via crowd sourcing and curated by materials subject matter experts (SME). Additionally, collaborative efforts with professional societies and other organizations (e.g. ASTM terminology standards, CEN, ASM, TMS, etc.) could be used to accelerate vocabulary/ontology development. Over time, multiple vocabularies would likely winnow down to key sets of generally accepted terms and mappings between terms having the same meaning.

Taxonomies, a form of ontology, can express simple relationships in the materials domain. More sophisticated relationships between materials processing, structure and properties can be expressed using complex ontologies. These ontologies need to be developed and implemented using World Wide Web Consortium (W3C) recommendations like RDF/OWL or widely accepted semantic technology standards such as time.owl and DC.

As the above elements are being established on a larger scale, various forms of materials informatics could be developed to greatly expand the materials data and design space for the materials scientists and engineers. Success requires innovative approaches during the development of agents to query linked materials data, applications to mash-up and integrate data, and reasoning/inferencing engines specifically tailored to the materials domain. Machine learning and other innovative "data hungry" approaches to extract knowledge could be developed and applied for materials design.

PHASE I: Develop a proof-of-concept for semantically linked materials data and information to include vocabularies/ontologies. Use these technologies to demonstrate sophisticated semantic queries for materials data and information. Develop approaches for increasing ontology richness, capturing provenance and ensuring appropriate access to restricted linked materials data (e.g. export controlled or Intellectual Property). Consider how the system could expand to accommodate manufacturing and component design.

PHASE II: Develop a robust midlevel materials ontology ready for crowd sourcing and initial experimental research use. Explore more sophisticated low level ontologies. Significantly expand the size of or integration across data stores. Propose and demonstrate computational approaches for establishing provenance and processing restricted linked materials data and information. Provide examples of integration with manufacturing or component design domains.

PHASE III: Use the Phase II work to fully develop an operational crowd sourcing materials ontology, linked-data capability to support the open materials research and development community. Develop linkages to manufacturing and component design domain.

PRIVATE SECTOR COMMERCIAL POTENTIAL/DUAL-USE APPLICATIONS: There is a growing realization that that vast amounts of historical and future materials development data is a valuable untapped resource for materials design. Those who support the development of a linked materials data concept and develop the tools to organize, relate, digest and synthesize the vast amount of materials data will likely find a welcome demand for their products from the community of materials designers, product designers and manufacturers in both the private and public sectors.

REFERENCES:
1. National Research Council. Integrated Computational Materials Engineering: A Transformational Discipline for Improved Competitiveness and National Security. Washington, DC: The National Academies Press, 2008. http://www.nap.edu/catalog.php?record_id=12199

2. Tom Heath, Christian Bizer, "Linked Data – Evolving the Web into a Global Data Space," Morgan & Claypool, 2011, DOI: 10.2200/S00334ED1V01Y201102WBE001

3. European Committee for Standardization (CEN), A Guide to the Development and Use of Standards Compliant Data Formats for Engineering Materials Test Data, CWA 16200, September 2010, ftp://ftp.cen.eu/CEN/Sectors/List/ICT/CWAs/CWA16200_2010_ELSSI.pdf

KEYWORDS: semantic technology, semantic web, semantic web stack, linked data, RDF, OWL, reasoning engines, provenance

OSD13-C03 TITLE: Making Practical Use of Electromagnetic Fields in Materials Processing and Applications

TECHNOLOGY AREAS: Materials/Processes

OBJECTIVE: Develop predictive computational models/tools to exploit the effect of electromagnetic fields in materials processing that enables tailored polycrystalline microstructures, enhanced properties, and shortened materials development cycles beyond the current state-of-the-art.

DESCRIPTION: The Army is interested in applying external physics-based fields during the processing of materials to develop enhanced properties and performance that is otherwise unachievable by conventional processing methods. The use of electromagnetic (EM) fields in materials processing and in controlling properties during their application has the potential to increase affordably, engender materials with unique properties, and to produce a specific property over the duration of field application (i.e., property selection on demand). The targeted physical and mechanical properties identified for enhancement may include but should not be limited to strength, hardness, fracture toughness, elastic modulus, or fatigue life. While numerous field-assisted methods have been experimentally explored over the years, the ability to simulate the effect that these fields have on the microstructure and, in turn, the properties and performance are not as prevalent. In order for computational methods to succeed in this endeavor, they must be able to capture the fundamental physics associated with how these field effects couple to, interact with, and affect the underlying microstructure and, hence, the resultant properties of the material. The goal of this SBIR is to develop the computational framework, models, and tools necessary to predict behavior under field effects and to design new materials using field effects with properties that are otherwise not achievable using conventional processing techniques.

Of particular interest in this SBIR is utilizing electromagnetic fields to engineer the microstructure and properties of polycrystalline metals for defense-related applications. The polycrystalline materials targeted for this work include conventional aluminum, copper, iron, tungsten, titanium, or magnesium alloys. The processing applications of interest for these models, with and without electromagnetic fields, include heat treatment and annealing of conventional metal alloys; electrodeposition, mechanical milling, or nanocrystallization processes for generating ultrafine grained and nanocrystalline materials; relieving residual stresses imposed during processing; surface mechanical attrition treatment (SMAT) techniques, shot peening, burnishing, etc. Previous literature has focused on how electromagnetic fields have been used to exert influence on metallurgical phenomena, such as grain boundary migration, grain boundary segregation, formation of texture, recrystallization, precipitation, phase transformation and sintering. For example, high magnetic fields have been used to both suppress abnormal grain growth and engineer the grain boundary character distribution of polycrystals.

PHASE I: The goal of Phase I is to develop a physics-based computational model that can predict the evolution of microstructure and properties under intense electromagnetic fields during material processing. This model will be used to develop novel materials with tailored microstructures and properties to address Army materials needs or goals. The deliverables for Phase I are (1) a validated computational model that is capable of predicting the effect of electromagnetic fields and resulting changes in processing path on material properties, (2) the data created or used to validate this model, and (3) a physical example of applying this model to a material system demonstrating a quantifiable change in properties of the selected material system. Execute a strategy that incorporates materials of interest and process-specific technologies while providing self-identified and challenging but achievable goals that target Army interests.

PHASE II: The goal of Phase II is to provide additional research and development of methodologies that will culminate in a validated software tool for predicting microstructure and properties in multiple alloy systems that meet or exceed current/future Army materials criteria. In this phase, it is envisioned that the computational models will be further extended by validating for multiple alloy systems of interest, performing parameter sensitivity studies and uncertainty analysis for the model, and utilizing within a robust design optimization framework with uncertainty to obtain optimal processing paths with electromagnetic fields in an effort to target different customized microstructures and material property specifications. The computational model should be packaged as software or as optional add-on modules in existing commercial software products.

PHASE III: The goal of Phase III is to commercialize the developed capability for tailoring microstructures and properties subjected to intense electromagnetic fields. This phase should clearly demonstrate the return on investment from utilizing the developed computational capability to achieve/improve material properties.

PRIVATE SECTOR COMMERCIAL POTENTIAL/DUAL-USE APPLICATIONS: The underlying technology(ies) associated with this topic are broadly applicable to all materials that require thermal processing and are physically receptive to electromagnetic fields. The potential advantages of the processing technology, including energy savings, properties control and tailoring, and small volume production are equally valuable to both commercial and defense manufacture. Virtually all metals and many ceramics industries, even commodity industries, as well as commercial and defense aerospace, automotive, and ship industries could benefit.

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KEYWORDS: Integrated Computational Materials Engineering, Field Effects, Material Properties, Tailored Microstructures, Electromagnetic, Materials Design, Processing-Structure-Property Relationship

OSD13-C04 TITLE: Stochastic Modeling for Structural Materials Properties

TECHNOLOGY AREAS: Materials/Processes

OBJECTIVE: The objective of this project is to design and develop a modeling tool for materials designers, which uses as input on the microstructure quantitative statistical measures of structure variations and features, and provides efficiently information on materials behavior with robust quantitative measures of performance variations and their correlations with microstructure features. This project supports the goals of the Materials Genome Initiative (MGI) in the area of Integrated Computational Materials Engineering (ICME).

DESCRIPTION: The behavior of individual crystalline grains in a material is well modeled and understood. For the behavior of polycrystalline media, however, we revert to relatively simple bulk constitutive models that often only roughly approximate our observations of macroscopic behavior. Local misorientations result in deviations in local responses, which can be much larger than any other deviations seen in analysis. Aggravating this is that these field problems are non-linear in the materials properties, which limits the applicability of many perturbation and spectral approaches. Finally, the exact grain positions and orientations are usually random, which makes single examinations of example microstructures limited in overall applicability for a materials design problem. More important to the designer is a measure of the mean behavior with quantitative predictions of the likely deviations, the correlations of these deviations, and the sensitivities of these deviations to the microstructure features. These allow the designer to make predictions of the reliability of the material.

The objectives of this research area are to design and develop a stochastic analysis code (for example, finite element analysis, boundary element analysis, peridynamics), using as inputs the statistical properties of the microstructure of the material, and outputting the performance characteristics, including variations, fluctuations, and correlations in materials behavior. The code should allow the design and development of random-field constitutive behavior models based on adaptations of homogenization of crystal plasticity models, or other similar mechanism-based models, that provide statistical information on material behavior at the polycrystalline length scale, and are suitable for insertion into stochastic analysis models. Objective outcomes should include the design and development of visualization tools that use robust archival data formats, and display mean-field, uncertainty, and sensitivity parameters, in a manner suitable to a materials designer. The research should also develop and design a suite of test and evaluation methods to determine experimentally the materials properties parameters necessary to populate the constitutive models (such methods might be reentrant). This work will utilize the construct of integrated computational materials engineering, supporting the development of the materials innovation infrastructure within the Materials Genome Initiative.

PHASE I: The successful phase 1 effort will demonstrate successfully the concept and mathematical basis for the code and its use in materials and product design to meet the objectives stated above. The effort shall also produce a roadmap/timeline for the code development and testing.

PHASE II: The Phase II project will develop and demonstrate the code the concept from Phase I. The investigators will demonstrate the uses of the code in the design of a hypothetical component of interest. The investigators will also outline a market for the tool, and a plan for a second iteration of development to meet that market.

PHASE III: The design of critical components requires careful consideration of the reliability of the components in the likely service environments. The designer, having a means of dealing directly with the randomness of the material and the environment, can consider the reliability issues as part of the design process, and not as an a posteriori process. This will speed the design process and result in systems optimized for superior reliability.

PRIVATE SECTOR COMMERCIAL POTENTIAL/DUAL-USE APPLICATIONS: Computational design of materials and materials systems for specific applications has been associated with both commercial and military materials processing and design programs and product development activities. The computational design of metal alloy microstructure or hybrid and composite material meso-structure and, therefore, properties appropriate for specific applications has broad application in both military platforms and civil transportation for air, sea, and ground vehicles and in dual-use specialty applications such as spacecraft and missiles. The potential to tailor specific metal alloy properties has the potential for more efficient use of materials and processing energy in both the defense and commercial sectors.

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KEYWORDS: Materials Genome Initiative, MGI; integrated computational materials science and engineering, ICSME, ICME

OSD13-C05 TITLE: Design Automation Software for Integrated Nanophotonics

TECHNOLOGY AREAS: Materials/Processes

OBJECTIVE: Develop and validate next generation system-on-chip electronic-photonic system simulation tools.

DESCRIPTION: Today, the military and commercial application spaces for silicon photonics are expanding very rapidly. The first wave of commercial products are aimed at the telecommunications and data communications spaces, but applications in biosensing, analog data processing, coherent systems, laser ranging, and many other areas are rapidly emerging.

One of the central pillars of the electronics industry is the electronic design automation infrastructure. A wide range of very sophisticated software is available for modeling electronic circuits. This ranges from TCAD, which is used to design the actual transistors, to SPICE, which is used to design analog circuits and elements, up to a wide variety of digital tools at the circuit and system level. These tools are crucial for managing the complexity of electronic circuit designs, and they enable IP reuse and rapid design iteration, while radically reducing experimental and test risk.

By contrast, the simulation tools for photonics and more specifically, silicon photonics, are extremely primitive. FDTD and finite element tools are adequate for device design, and have become quite mature. The tools from the TCAD world are quite adequate for modeling active devices like modulators and photodetectors. But the higher-level, system-oriented tools are extremely immature compared to what is available in electronics. There is a substantial opportunity for new approaches to this problem. Of particular interest are approaches that meet the following key requirements: (1) Close, seamless integration between standard electronic design automation environments and optical device simulation; (2) Hierarchical abstraction into compact models of the key device physics; (3) Design-for-test integration; (4) Ability to easily change the tradeoff between the level of physical detail being modeled and the speed of the simulation; (5) Ability to simulate in both frequency (small-signal) and time domains (large signal); and (6) Use or development of associated model definition standards

Design kits for photonic integrated circuits already exist and are available from various foundries. Proposers are required to make use of existing design kits, supporting at a minimum high speed (20G or above) modulators, detectors and waveguides. Integration with electronic RFIC PDK's is desirable.

PHASE I: Develop and demonstrate plausibility of an approach to simulating complex silicon electronic-photonic systems through a compact-modeling approach, integrated with existing EDA tools. Develop designs for an analog or RF (not purely digital) verification circuit.

PHASE II: Fabricate the circuit developed in phase I, and test it to validate the tool flow developed in phase 1. Share the full details of this design with the wider community as a tutorial, including the full details of the design flow and the design itself.

PHASE III: Use the developed tools to demonstrate high performance components for RF signal processing, radar, imaging systems and/or high speed communications.

PRIVATE SECTOR COMMERCIAL POTENTIAL/DUAL-USE APPLICATIONS:
Military application: Military applications include RF signal processing, radar, imaging systems and high speed communications. Commercial applications: High performance computing, telecommunications, networking, data processing.

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KEYWORDS: integrated photonics, interconnects, designs for analog system, designs for RF system, system-on-chip, electronic-photonic system simulation tools, simulation tools, design automation software, design kits, EDA tools, foundry, SPICE, photonic SPICE

OSD13-EP1 TITLE: <u>Phase Change Thermal Buffers for Environmental Control Unit Efficiency Improvement</u>

TECHNOLOGY AREAS: Ground/Sea Vehicles, Materials/Processes

OBJECTIVE: Develop and demonstrate a phase change material based thermal buffer to enable ‘rightsizing’ of environmental control units (ECUs) and improve overall efficiency through reduced peak loads, more stabilized ECU operation, and off-peak thermal energy storage.

DESCRIPTION: Military Environmental Control Units (ECUs) represent one of the dominant energy users in forward operating environments, and significant effort is being made to improving overall ECU efficiency [1]. Reducing overall Size, Weight and Power (SWaP) of military ECU’s is complicated by the transient, yet predictable, nature of the thermal demand profile over the course of a typical daily usage cycle, where cooling capacity must currently be set to match the daily peak load. This need for cooling unit exess-capacity creates trickle-down effects of increasing installed power generation requirements and logistic transport burdens. ECU capacity “right-sizing” can help meet Operational Energy Strategy requirements for improved net energy efficiency, but will demand significant changes to ECU design.

Thermal Energy Storage (TES) has been shown to be effective in load-leveling the daily cooling profile for fixed facilities, providing reductions in net energy consumption in some cases due to ‘free cooling’ [2], as well as reduced compressor cycling, more steady cooling, and reduced peak power requirements [3,4]. However, because of the compositional variability in cooled facilities in forward operating environments, implementing TES would require directly integrating the technology within mobile ECUs, a task which has received only cursory attention in the literature and would require optimization of overall size and weight in addition to reducing energy usage. Solid-liquid Phase Change Materials (PCMs) present one high-density TES option for cooling systems and environmental control [5,6], yet challenges remain in material selection, heat exchanger topology and integration strategy to maximize operational benefit.

This SBIR program seeks to develop a PCM-based solution to enhance the performance of an existing ECU in the 9-18k BTUH range, addressing concerns of system energy density, material compatibility, and failure modes due to repeated thermal cycling. Offeror is expected to propose a phase change TES component that can be integrated into an existing ECU for the purpose of off-peak load leveling or demand reduction, with a target energy usage reduction of 5-10% over an average daily cycle, assuming no more than an 25F diurnal temperature variation. Unit should still be able to provide rated cooling capacity under worse case conditions in a deployed environment (design condition 125F ambient, 90F indoor dry bulb, 75F indoor wet bulb) for a period of at least 2 hours during daily peak demand period. Specification of PCM type, integration point (on refrigerant or air-side flow paths), storage temperature, and storage heat exchanger design are left up to the offeror, however those decisions and the associated impact on overall system size, weight and performance should be justified through thermodynamic analysis and system/component modeling.

PHASE I: Offeror will demonstrate through simulation or experimentation the feasibility of combining thermal energy storage with an existing compact environmental control unit to achieve a 5-10% net energy usage reduction. If not demonstrated experimentally, performance simulation should convincingly account for non-ideal heat transfer, material and and thermodynamic conditions. Overall increase to ECU size and weight tradeoff with cooling capacity gain should be captured. During this phase commercialization aspects must be considered and potential plans for commercialization elucidated.

PHASE II: Demonstrate a fully functioning prototype system using the concept developed in Phase I. Performance should also be measured under varying ambient conditions to ascertain performance sensitivities, and offeror should evaluate design scalability to larger capacity ECUs. Validate analytical and numerical models developed in Phase I.

PHASE III: Design and develop phase change TES units for ECUs using the knowledge gained during Phases I and II, targeting integration into PM MEP Improved ECU (IECU) systems. This series of ECUs must meet military unique requirements, e.g. shock, vibration, and environmental variability.

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KEYWORDS: thermal buffers, environmental control unit, thermal energy, phase change materials, heat exchanger

OSD13-EP2 TITLE: High Efficiency Electric Power Manager for Man-Portable Photovoltaic Systems

TECHNOLOGY AREAS: Ground/Sea Vehicles, Materials/Processes

OBJECTIVE: Develop and demonstrate an electric power management system that will couple low power photovoltaic (PV) energy generating devices with a Li-ion battery with at least 96% module efficiency.

DESCRIPTION: Renewable energy, specifically photovoltaic, is an attractive technology for man-portable power sources and tactical applications. However, to be effective as a system, it is necessary to have a power manager that can efficiently couple a small solar array (~20W) to a battery such as the BB2590. Power managers are already being fielded with PV sources, but their usefulness has been limited by the design of the power manager. The goal of this topic is to develop a cost-effective, lightweight power manager that displays high efficiencies for low power modules in a user-friendly format that can rapidly charge a BB2590. In addition, given the nature of Li-ion batteries, maximum use of solar input is achieved when multiple batteries are charged in parallel, so a power manager is sought that can charge multiple batteries simultaneously. Other capabilities that will benefit the system are scavenge mode, buck/ boost capability, high-speed maximum point tracking, reduced heat and IR signature, a wide operating temperature range, charging capability in low light (<0.1W input power), and near loss-less power transfer.

PHASE I: Produce a design for a power manager that can charge multiple BB2590 batteries in parallel demonstrating greater than 96% power transfer efficiency, battery loss of less than 8% for 1 year of standby, weighing less than 235g and costing less than $600.

PHASE II: Fabricate and test the power manager designed in Phase I. Measure and validate performance across various load profiles and generation regimes, including scavenge mode. Incorporate additional capabilities, including buck/boost capability, networking capability, and maximum point tracking.

PHASE III: Develop prototype production line for the power manager and commercialization plans using the knowledge gained during Phases I and II.

PRIVATE SECTOR COMMERCIAL POTENTIAL: Cost effective, efficient, power managers have many applications working with commercial photovoltaic and energy-scavenging systems.

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Journal of Photovoltaics, Vol. 3, No. 1, p 535-541 January 2013

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KEYWORDS: Power Management, Energy Conversion, Solar Power, Photovoltaics, Alternative Energy

OSD13-EP3 TITLE: High Efficiency Flexible Photovoltaics

TECHNOLOGY AREAS: Ground/Sea Vehicles, Materials/Processes

OBJECTIVE: Develop and demonstrate photovoltaic arrays that are flexible and can achieve greater than 20% solar photon to electrical conversion efficiency in a lightweight configuration.

DESCRIPTION: Photovoltaics (solar cells) are an attractive technology to provide renewable energy sources for forward operating bases, man-portable power sources, and tactical applications. Solar arrays can provide base power greatly reducing the need for logistical fuels, continuous battery recharging for warfighters on the move, and integrated power sources for remote, autonomous systems, e.g. UAVs. To be effective, solar arrays must be lightweight, flexible, and provide high power density. Flexible solar arrays based on thin film photovoltaics have been fielded for some military applications, but their usefulness has been limited by their low efficiency. Si panels have attained efficiencies as high as 22% but but are made of glass and Al. Flexible amorphous Si or polycrystalline CIGS panels are less than 15% efficient. Higher efficiency, flexible solar cells have been demonstrated for space applications, but their cost has hindered terrestrial applications. New materials and manufacturing methodologies are needed to produce a solar cell that is lightweight, flexible, high efficiency, and affordable. The goal of this topic is to develop cost-effective, photovoltaic technologies that display high efficiencies in a flexible format.

PHASE I: Produce a design for a flexible (bend radius of 6” or less) solar cell and array that can achieve >20% terrestrial conversion efficiency at ~1W/g, with a cost target of $50/W or less using modeling and simulation supported by material parameter data and optoelectronic measurements on representative materials and test structures.

PHASE II: Grow, fabricate and test the solar cell design developed in Phase I. Quantify the solar cell performance through illuminated and dark current vs. voltage measurements and spectral response measurements. Develop methods to improve solar cell performance and optimize the solar cell design accordingly. Demonstrate a solar array coupon consisting of at least 4 interconnected solar cells, measure the performance, and compare with predictions from Phase I. Develop methods to improve solar array performance and optimize the array design accordingly.

PHASE III: Using the knowledge gained during Phases I and II, produce 5 prototype solar arrays that each produce at least 20W. Develop prototype production line for the fabrication of high efficiency, flexible solar arrays and commercialization plans.

PRIVATE SECTOR COMMERCIAL POTENTIAL: Cost effective, high efficiency, flexible solar cells could be used as lightweight, portable power sources.

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KEYWORDS: Photovoltaics, Power Generation, Energy Conversion, Alternative Energy, Solar Power

OSD13-EP4 TITLE: Ultra-High Power Density Solid Oxide Fuel Cell Stack for High Efficiency Propulsion and Power Systems

TECHNOLOGY AREAS: Ground/Sea Vehicles, Materials/Processes

OBJECTIVE: To develop an ultra-high power dense solid oxide fuel cell (SOFC) stack (>500 W/kg) capable of supporting high efficiency, logistic-fueled propulsion and power systems for small autonomous vehicles and mobile power generation.

DESCRIPTION: Small unmanned aerial systems (S-UAS), unmanned ground systems (UGS), vehicle auxiliary power units (APU), and mobile power generation units require high efficiency power systems capable of operating on logistically available fuels (JP-8, diesel) to enable long endurance operation. In particular, S-UASs in the Group 2 (21 – 55 lbs)/Group 3 (<1,320 lbs) range and UGSs such as the Battlefield Extraction-Assist Robot (BEAR) have a critical need for high efficiency, reliable propulsion system options capable of operation on logistically available fuels. SOFC-based systems have shown promise to meet these needs, with the potential for 30% - 45% thermal efficiency and 1000's of hrs of operational life, compared to < 20% thermal efficiency and 100's of hr of operational life for baseline internal combustion (IC) engine-based propulsion systems within this size class. The main drawback is the lower system-level power density (~100 W/kg compared to ~1000 W/kg for a typical IC engine), which limits the applicability of such systems. For a typical SOFC-based system, the stack represents 30 - 40% of the system weight, assuming a stack power density of 200-300 W/kg. If the stack power density is increased to 500 – 1000 W/kg, this would facilitate a 2X-4X increase in the system-level power density (i.e. 200 – 400 W/kg). This, when combined with the increased fuel efficiency, would enable an SOFC-based propulsion system to meet and/or exceed IC engine performance [1]. For example a 200 W/kg SOFC-based propulsion system at 30% efficiency would have comparable endurance to 1000 W/kg IC engine-based system at 20% efficiency, with the potential for increased reliability and operational lifetime.

A number of SOFC concepts have been demonstrated at the button cell level, such as low-temperature (LT)-SOFCs [2], metal-supported SOFCs [3], or others; which have the potential to meet these power density goals. The main challenge is exploring the feasibility of scaling up these novel concepts to the stack level while maintaining the same level of power density. For example, LT-SOFCs which have been demonstrated at ~2W/cm2 on the cell level are projected to produce a stack at ~3000W/kg. This projection, though, does not take into account the many issues which can lead to efficiency losses at the stack level, such as: interconnect resistance, interfacial gradients, fuel utilization, etc. The focus of this topic is to demonstrate the scalability of the novel cell-level technology to the larger area cell level (> 150 cm2 active area) in the Phase I and then to the stack level (500W – 3 kW) in the Phase II in order to determine the feasibility for integration into a complete SOFC power system. There is a particular interest in potential stack technologies which prove to be flexible to fuel reformate composition and tolerant to fuel impurities, such as sulfur content.

PHASE I: Demonstrate a novel SOFC concept on a large-area cell (> 150 cm2) at high power density (> 1 W/cm2) operating on desulfurized logistic fuel reformate. Develop initial concepts and designs for scaling up to a full SOFC stack (500W – 3 kW) capable of high power density (> 500 W/kg) operation. Define any unique interface and/or operational constraints particular to running this fuel cell technology in a system.

PHASE II: Demonstrate an SOFC stack (> 500W, objective > 3 kW) capable of a high power density > 500W/kg (objective > 1000 W/kg) on desulfurized logistic fuel reformate, with an objective of utilizing sulfur-containing reformate.

PHASE III: Work with a system developer to integrate this technology into a logistic fueled (JP-8, Diesel) power and/or propulsion system capable of 2 kW – 10 kW net power output.

DUAL USE COMMERICIALIZATION: Military applications include S-UAS and UGS propulsion systems, ground vehicle and ship board APUs, and squad to platoon level power generation systems. Potential commercial applications include Class 8 Truck APUs and remote site power generation.

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KEYWORDS: Fuel Cell, Solid Oxide Fuel Cell, Logistic Fuels

OSD13-EP5 TITLE: Precision In-Cylinder Pressure Sensor System for Heavy Duty Diesel Engines

TECHNOLOGY AREAS: Ground/Sea Vehicles

OBJECTIVE: Develop a high data-rate real-time pressure measurement system to continuously measure combustion pressure in diesel engine cylinders, which is affordable, durable, and accurate, for future use in real-time adaptive engine controls of fuel injection.

BACKGROUND/DESCRIPTION: Unlike commercial diesel engines which are typically designed to operate on a single fuel such as U.S. ultra-low sulfur highway diesel (ULSD), military engines must be able to operate on a variety of distillate fuels, typically jet and worldwide diesel fuels, due to worldwide deployments. Most U.S. military diesel engines are adapted commercial engines and have no ability to compensate for the varying properties among jet (JP-8, JP-5, Jet-A1, and others) and worldwide diesel fuels. Jet fuels, which are otherwise similar to arctic diesel fuels, pose a particular problem because the cetane index, a measure of a diesel fuel's tendency to ignite upon injection, is not controlled in jet fuels (except in recent synthetic jet fuel blend specifications) and is typically low. A low cetane index causes power loss, inefficient combustion, poor low-temperature starting and in severe cases, damage due to excessive chamber pressures.

Real-time adaptive electronic engine controls could manage these effects by adjusting diesel fuel injection timing and rate according to fuel combustion performance, but a high data-rate system to continuously measure combustion pressure is needed to provide input data. The system must be affordable, durable and accurate, and detect explosive combustion events which can occur with very low cetane fuels. By closely monitoring and controlling combustion pressure in real-time, a military engine control will adapt on-the-fly to fuels with a broad range of ignition properties, allowing military engines to attain high power output and efficiency despite variable fuel properties. Sensors with the desired sensing capability are now used in diesel engine laboratory research, but they are large, costly and not designed for use in vehicles.

Because the integral of combustion pressure and volume reveals the work produced in a single firing event, data from the high-speed pressure sensor makes it possible for an engine control, using crank position data to determine piston travel, to determine precisely how to adjust diesel injection timing to get maximum efficiency from an injected unit of fuel.

When used in commercial engines, high speed precision pressure measurement will allow engine control units to better control nitrogen oxide, hydrocarbon and smoke emissions by precisely managing the fuel injection timing and quantity to attain the optimal pressure-temperature profile in each combustion event. This will enable smaller exhaust gas recirculation (EGR) flows, reducing the parasitic power burden used for EGR cooling and recovering some of the engine efficiency that is currently lost to EGR implementation.

PHASE I: Design

1. The contractor shall design a high data-rate pressure sensor that continuously and directly measures individual cylinder combustion pressures in diesel engines, and the corresponding data acquisition system.

1.1 The sensor shall measure with +/- 1% accuracy over the pressure range 0-350 bar, and shall be capable of measuring at 27,000 readings per second, equivalent to one measurement per degree of crank angle rotation in an engine running at 4500 revolutions per minute. The sensor shall also be able to measure a pressure rise rate of at least 810 bar per millisecond in order to detect explosive combustion events.

1.2 The sensor shall be designed for a working life of 10,000 hours.

1.3 The sensor tip shall have no more than a 4 millimeter (mm) diameter exposed face in the combustion chamber, shall not protrude into the combustion volume and shall not alter fuel injection spray patterns.

1.4 The installed sensor shall filter out the effects of engine vibration, and must be immune to carbon fouling and combustion chamber temperatures in its mounting location.

1.5 The contractor shall show by analysis and experiment that the physical principles of the sensor design are feasible for use in a cylinder pressure sensor. The contractor shall build a test article that is based on the sensor's operating principle, and show that the sensor is feasible at room temperature and the intended operating pressures and frequencies.

1.6 The contractor shall design a data acquisition system for the high data-rate sensor that can receive a total of up to 27,000 measurements per second from up to twelve engine cylinders simultaneously and can output digital pressure data for each engine cylinder in a form usable by an electronic diesel engine control system. The data acquisition system shall be designed to operate on 24 volts DC power.

1.7 The data acquisition system design shall include cabling or other communications means between the sensors and the data acquisition system and the cabling shall be designed to be durable in a heavy vehicle engine compartment environment.

1.8 The complete sensor and data acquisition system shall be designed for a target cost of $300, based on a variant intended for installation in a six-cylinder commercial truck engine.

PHASE II: Demonstration

2. The contractor shall build and demonstrate the sensor and data acquisition system designed in paragraphs 1.1 -1.6 above.

2.1 The sensors and data acquisition system shall be demonstrated on a multi-cylinder diesel engine in a test cell environment. The demonstration will not require any actual control of the engine or interaction with the engine controller.
2.2 The contractor shall demonstrate that the data acquisition system can support twelve sensors in operation, but

demonstration on an engine is not required.

CONTRACT DELIVERABLES:
a. Monthly technical reports in letter format, with a financial report of actual vs planned spending.
b. Final technical report with conceptual drawings of the sensor and cabling.
c. One complete set of six sensors, and a sensor data acquisition system for government testing.
d. Documentation of the algorithms used for the data acquisition system, the data output format, and a government-editable version of the data acquisition system software with documentation sufficient to enable government engineers to load, operate and save modified versions of the software.

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KEYWORDS: Pressure sensor; diesel engine; engine cylinder; exhaust gas recirculation; cylinder pressure

OSD13-HS1 TITLE: Advanced Programming and Teaching Interfaces for Autonomous System Control

TECHNOLOGY AREAS: Information Systems, Human Systems

OBJECTIVE: Develop interface(s) to allow users to "teach" or program robotic manipulation and mobility through virtual simulation and through real-world demonstration which the robot can apply autonomously in various situations.

DESCRIPTION: It is not likely that an autonomous system can be programmed with all the information it requires to perform every mission or every variation of every contingency within the near future. One way to address this issue is to provide user-friendly means to teach or program a robot to add to its autonomous capability. This proposal focuses on the physical aspects of the robot performance, manipulation and mobility, and the combination of the two, whole-body manipulation.1 Optimally, one would teach a robot as one would teach a human how to perform a physical task. Since this would be an initial entry into intuitive user friendly methods to teach a robot to perform complex physical acts, it is advisable to start with a virtual representation or simulation that lay the foundation for the interface and programming syntax that would describe the physical actions of the robot.2 Programming a robot to use a new tool provides a good example where "teaching" will prove beneficial. There are issues with teaching proper grasp of the tool, and the proper pose that would allow the robot to use the tool effectively and apply forces that would not damage the object(s) the tool is acting upon, the tool, or the robot. Thus, before the issues of the human interface are addressed, the basic issues of control for a dynamic multi-body system must be solved in manner that can be represented as a form that can be programmed into a robot.2,3

Focus should be placed first on the development of a software architecture that encompasses and integrates task and motion planning for whole body manipulation. The software should have the ability to program a robot to perform physical tasks through a virtual environment capable of modeling dynamics and physical contact/interaction without the need for a user such as a Soldier to write a "C-level" program. However, the programming constructs or "subroutines" created by this architecture to operate the robot must be accessible and usable in common programming languages such as C/C++ and Python as open architecture libraries and subroutines. The newly learned behavior must be of a structure that the robot can incorporate it into its existing control programming and implement it autonomously. It is expected that in order to implement the virtual environment model of the robot which would include descriptions of its physical configurations, actuators, and sensors, highly trained and educated personnel may be needed. The virtual model should be of a fidelity that allows control for a dynamic multi-body system to be developed. However, once the detailed model is implemented in the virtual environment, the software should provide an interface that allows a user such as a Soldier to interact with and program a robot through the virtual environment to perform a physical task such as grasping or repetitive tasks such as sweeping for mines and IEDs, and trenching for wires.

A secondary focus should be to develop an open software architecture that can be built upon and evolve through time that will allow DoD, Universities, and private industry to collaborate as a software development community on this problem. Open architecture efforts such as ROS should serve as an example. There should be interfaces for well-established speech recognition and vision libraries such as OpenCV. It is expected that the architecture will allow for future advancements to be added. For example there are different methodologies for "teaching" how to recognize a physical object. 4 The open software architecture should have the proper interface to allow object and feature recognition packages/algorithms to be added and updated.

PHASE I: The deliverables should include a final Phase I report that describes a feasibility concept that encompasses the architecture, algorithms and hardware needed to implement graphical and visual input to script an act of whole body manipulation, that can be implemented as part of a library describing autonomous motion for a robot. Requirements for graphical input or interface for physics-based virtual robot models must also be documented. The feasibility concept should include a description of software interface architecture for future expandability.

PHASE II: Phase II shall produce and deliver a prototype system for teaching a robot to perform mobility, manipulation and whole-body manipulation. The Phase II system shall be demonstrated to operate as a simulation of an actual robotic platform. The control constructs generated by the prototype teaching software will be used to program tasks in which the robot will need to interact with objects and the environment using whole body manipulation. The user should not need to write a text-based program. However it should be demonstrated that the robot control constructs generated may be used as libraries in "C/C++" code. Also to be demonstrated is the learned behavior being implemented in a manner in which the robot may use the behavior in conjunction with its previous programming.

The prototype system should include:
- A documented open architecture framework and algorithms that allows additions and modifications to autonomous manipulation, mobility, and whole-body manipulation control.
- Prototype simulation software to augment the learning process with open architecture interfaces for programming a robot capable of implementing whole-body manipulation.
- Demonstrations of learned/modified autonomous whole body manipulation behavior.

The virtual environment software and interface hardware developed should be compatible with RS JPO interoperability standards. The architecture and algorithms for robot control will be fully documented. The source code will be made available to DoD employees. Source code will follow common standards of open source programming and be compatible with ROS.

PHASE III: DUAL USE COMMERCIALIZATION: Research could be transitioned to DoD and first responder efforts, or University research programs. Robots in industry may be programmed for adaptability to changes in the fabrication process. If the software is adopted as a standard, it may allow a descriptive verbal language for instructing robots to develop. Better operator interfaces should reduce the skill level required to program robots for enhanced robot autonomous operation adaptability. This is especially true for advanced robot control concepts.

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KEYWORDS: Autonomy, Control, Manipulation, Whole body manipulation, Dynamic manipulation, Robot, Simulation, Programming, Human Interface, Adaptive Control

OSD13-HS2 TITLE: Virtual Verification Test Bed for Robust Autonomous Software Operation in Complex, Unknown Environments

TECHNOLOGY AREAS: Information Systems, Human Systems

The technology within this topic is restricted under the International Traffic in Arms Regulation (ITAR), which controls the export and import of defense-related material and services. Offerors must disclose any proposed use of foreign nationals, their country of origin, and what tasks each would accomplish in the statement of work in accordance with section 3.3 of the solicitation.

OBJECTIVE: Develop an innovative verification tool to assess the robustness of run time safety systems bounding autonomous and learning algorithms for operation in untrained/unknown environments.

DESCRIPTION: It is understood that an autonomous unmanned air, ground, or sea vehicles can incur a near infinite decision space that is difficult to capture completely in extensive simulation. The response of these vehicles to untrained environments can potentially have unintended consequences to adversely affect safety. This is of particular concern when these vehicles are considered for collaborative manned/unmanned teaming missions. For such systems, a run time verification engine may be developed to ensure the safety of human life by constraining the output of the autonomous algorithm to guarantee actions are correct, interpretable, and recoverable. The autonomous algorithm combined with the failsafe mechanism is intended to improve the robustness of autonomous systems to unknown environments and unexpected events. However, if such a failsafe/recovery mechanism existed, what evaluation systems are available to test their viability and robustness? The intent of this solicitation is to develop a verification method to examine the robustness of a run time safety algorithm.

The first objective is to examine the techniques presented in [1][2] and apply them to an autonomous unmanned vehicle model that includes a learning trajectory generation algorithm. The techniques in [1] present a method to protect the behavior of an adaptive / learning function. The techniques in [2][3] present methods to analyze the robustness of the implemented safety algorithm. Due to the dependence of autonomous systems on historical state data, current simulation environments require the need for extensive run times to reach a potential unintended operating region. Additionally, as a greater quantity of information is fused and utilized by the autonomous algorithm to make decisions, gradual, unintended data streams may induce state conditions that may cause an unsafe or unpredictable response. A key capability must be to rapidly re-stimulate the system to an untrained, unintended, or erroneous operating state in order to assess the robustness of the run time safety algorithm.

The verification algorithm must implement:
- A method to introduce specific logical or run time operating states that induce an algorithm failure.
- A mechanism for recording and initializing systems to specific states.
- An interface control description that emulates real world sensor outputs to be provided to the system under test.
- The generation of a robustness measure around an operating region [2][3].

PHASE I: The objective of the Phase I effort is to examine the robustness techniques presented in [2][3] and apply them to a run time protected [1] autonomous unmanned vehicle model to ensure safety of human life when cooperating with manned vehicles. It is expected that the offeror should have, at proposal, a Matlab (or similar) model of a representative autonomous unmanned vehicle and a learning algorithm present to decide new trajectories based on initial goals and changing environmental conditions. The Phase I effort shall include the development of a notional verification tool applying the techniques in [1][2], that includes a run time verification engine that only allows the learning system to traverse within a pre-defined safety boundary and that analyizes the robustness of the algorithm response.

The Phase I deliverables should include:

• A proof of concept model in Matlab (or similar) implementation of a runtime verification robustness analysis tool demonstrating feasibility and scalability of the approach.

• A Phase I final report that will include a full modeling and analysis tool conceptual system design and an implementation plan for the follow-on tool development.

PHASE II: The Phase II effort shall implement and extend the verification method. This tool will enable modeling of learning based unmanned systems and will generate test cases based upon user specified failure modes. These test cases will then be automatically run against the autonomy using the previously implemented communication interface and initial condition injection. The company must provide the capability to provide a robustness quantification metric that is updated as the model is subjected to new and unexpected behaviors according to the given requirements and safety specifications.

The Phase II prototype software should show proof-of-concept by applying the tool to a particular, relevant DoD use case. Of particular interest would be use cases that can be generalized across domains (e.g., Underwater vehicles) or include heterogeneous autonomous systems (e.g., air/ground/sea coordination).

PHASE III: DUAL USE COMMERCIALIZATION: Improved trust in robust autonomous systems will enable the use of complex learning algorithms in safety critical applications. Capability can be used in future government programs including applications in the Department of Defense, Transportation, and Energy that require robustness guarantees of future adaptive/learning autonomous vehicles operating in congested and safety critical environments. Capability can be used in future commercial programs, enabling the certification and transition of applications such as self-driving cars, autonomous cargo aircraft, etc.

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KEYWORDS: Autonomy, Perception, Collaboration, Test and Evaluation, Verification and Validation, Trust, Learning and Adaptive Control

OSD13-HS3 TITLE: Technologies for Low-Bandwidth, High-Latency Unmanned Ground Vehicle Control

TECHNOLOGY AREAS: Air Platform, Information Systems, Sensors, Human Systems

OBJECTIVE: Develop algorithmic approaches to enabling robust control of autonomous unmanned ground vehicles operating in complex, unstructured environments, over low-bandwidth, high latency communication links.

DESCRIPTION: This topic addresses the problem of robustly commanding and controlling unmanned ground vehicles operating in complex, unstructured environments. Current approaches to this task rely on dense scene reconstruction from a variety of sensor data such as LIDAR and video imagery. Scene representations are then relayed to a remote human operator who provides commands at varying levels of supervisory control (intelligent teleoperation).

Challenges arise in scenarios where the available communication link allows only low bandwidth data transmission and/or exhibits high latency. In such scenarios, bandwidth limitations prevent rich scene representations from being transmitted from the vehicle to the operator in a timely manner. In addition, high latency may have a destabilizing effect, causing commands issued by the operator to lead to unsafe actions by the vehicle. This effect is exacerbated as the frequency of command inputs increases.

Novel frameworks, and associated algorithms, are required to enable robust operations of autonomous unmanned ground vehicles operating in complex, unstructured environments, over a low-bandwidth, high latency communication link. Such approaches would provide an operator with sufficient information to make timely command and control decisions, even in harsh communication scenarios. They would also provide contingency-based assurance of system safety in the absence of timely command and control decisions. In addition, other functional relationships such as sensor costs need to be addressed since these costs are generally proportional to the level of autonomy or intelligence.

Approaches to this problem may emphasize perception, vehicle control, or some combination of the two. In the perception domain, approaches to intelligent data compression and minimal scene representation are desired [1]. Such approaches may condense raw sensor data into compact, human-recognizable primitives that can be efficiently transmitted over low-bandwidth communication links. These methods may be optimized for particular contexts (e.g. urban operations) to enable improved data compression, and they may also dynamically vary scene representation richness or complexity depending on available bandwidth.

In the control domain, contingency-based control algorithms that ensure vehicle safety in the absence of operator inputs, or when provided with unsafe command inputs (perhaps due to the effects of latency) are desired. Again, such approaches may be optimized for particular contexts to enable improved performance. Methods that act as vehicle "co-pilots", which both ensure vehicle safety and attempt to predict operator intent, would be particularly useful [2].

The output of this work is software that would be integrated with an existing autonomous vehicle(s) to yield measureable improvements in safety and operational speed compared to a baseline system, for the low-bandwidth, high-latency scenarios of interest. If successful, this work will have broad applications for autonomous and semi-autonomous military vehicle operations.

PHASE I: The goal of Phase I is to investigate the feasibility of developing algorithms that can robustly handle huge variations in both bandwidth and latency while still maintaining levels of overall mission control that are comprehensible to a human operator. On the unmanned ground vehicle side, these variations could in the worst case scenario transition within milliseconds from sufficiently high bandwidth and low enough latency to permit as-needed transitions into tele-operator mode, down to no communications at all. Upon such transitions, the unmanned ground vehicle should demonstrate an ability to replace direct human command with an emulation of human command that consists of some hierarchy (possibly very simple) of specific mission goals and navigation rules. On the human side, the mission supervisor software should similarly use its knowledge of the intent of the unmanned ground vehicle to provide the best possible visual representation of its likely status, including for example explicit graphical methods for representing growing uncertainty. Feasibility of the proposed framework/algorithmic approach(es) may be demonstrated through modeling and simulation for initial developmental verification. The Phase I deliverables shall include a final report detailing the algorithms, theory, and initial performance data. In addition, the final report should testing options for very diverse exploration of changing bandwidth and latency during the operation. The addition of noise is desirable but not required.

PHASE II: Phase II shall produce prototype software with focus on implementation and testing of the framework/algorithm(s) developed in Phase I. Phase II prototype verification shall be demonstrated through modeling and simulation with particular emphasis on proof-of-concept and performance. General testing shall execute options developed in Phase I concerning exploration of changing bandwidth and latency during operation. The prototype software system shall include:

- Fully documented framework/algorithms in open source with compatibility to ROS.
- Prototype demonstrations using Modeling and Simulation in a credible simulation environment, or an unmanned ground vehicle platform..
- Final Report detailing all development, design, and testing to include performance metrics.

PHASE III: Work in Phase III will focus on the transition of Phase II prototype software to a DoD relevant environment and platform(s). Specific DoD interface standards (e.g. RS-JPO Interoperability, JAUS, etc.) shall be implemented as necessary to permit adaption to various platforms. Potential commercial applications of this technology include commercial automotive.

DUAL USE APPLICATIONS: Unmanned ground vehicles have applications in numerous civilian domains, including mining, autonomous driving, hazardous site inspection, site security, and others. It is expected that the software developed here would have direct application in a variety of such domains.

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KEYWORDS: Unmanned Ground Vehicles, Autonomous Ground Vehicles, Vehicle Control, Vehicle Perception, Communications

OSD13-HS4 TITLE: Unmanned Systems Perception Workbench for Test and Evaluation

TECHNOLOGY AREAS: Information Systems, Sensors, Human Systems

OBJECTIVE: Develop an API and User Interface for testing and evaluating the performance of perception systems for autonomous vehicles.

DESCRIPTION: Perception systems for autonomous vehicles are often tuned to a specific platform and thus will degrade in performance if transferred to a different platform. For example, terrain costs are computed according to a fixed mapping from perceived terrain to robot capabilities. This means that upgrades or damage to the underlying platform can severely affect performance. Also, comparing perception systems on a single platform or across platforms is hampered by the lack of plug-and-play capability in most perception systems and tools for statistically meaningful evaluation.

The DARPA Learning Applied to Ground Vehicles (LAGR) program addressed this shortcoming in part by providing a single platform with a default control system and planning module to which a perception system could be added by plugging in a flash disk. They system was not transferrable, however, to other robot platforms, and there existed no common set of tools for evaluating the data collected by the robot.

It is desirable to be able to evaluate the relative performance of perception systems before the question of their effectiveness arises in the field. To this end, an Application Programming Interface (API) and User Interface are sought that will enable test of cross-platform generalizability of perception systems. The API should provide an interfacing standard that will allow perception systems to act as plug-ins to the autonomy software, communicating with the standardized planning system and controls. The user interface will enable an easy and intuitive way to conduct tests, visualize results, and do comparative analysis.

PHASE 1: Develop an API that enables simple integration of any perception system following the API's interfacing guidelines onto a test autonomous platform. Demonstrate on a COTS robot with a simple perception system doing ODOA by interfacing with the robot's provided planning and control system. Produce a design for a User Interface that enables visualization and analysis of the performance of the perception system. Develop the metrics to be used for comparison of systems. These should include metrics such as time-to-goal, number of hazards encountered, number of human interventions required, and power consumption. The Phase I deliverables should include a final Phase I report documenting and describing the API in the form of a software manual as well describing the design of the User Interface.

PHASE II: Develop the User Interface software designed in Phase I to allow convenient measurement and subsequent analysis of perception systems' performance including cross comparison of perception systems. Use the API and User Interface to demonstrate comparison of two perception algorithms across all metrics developed in Phase I on the COTS robot chosen in Phase I. The purpose of the API and User Interface is the evaluation and comparison of perception systems across platforms. To this end, extend this demonstration to include application of the API to a second COTS platform along with repeated demonstration of the two perception algorithms on this new platform.

PHASE III: Bring the User Interface to a commercial level. Transition the work of Phase II to DOD test centers and DoD development efforts that need to assess and pick the most competent perception systems available. Understanding the limitations of existing perception systems is essential for properly deploying them for the appropriate environments and tasks. Potential commercial applications of this technology include autonomous system development and evaluation within major UGY providers within the areas of agriculture and mining.

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KEYWORDS: Autonomy, Comparative Analysis, Perception, Unmanned Vehicles, Engineering Test

OSD13-HS5 TITLE: Human/Autonomous-System Interaction and Collaboration

TECHNOLOGY AREAS: Air Platform, Information Systems, Human Systems

OBJECTIVE: Develop innovative frameworks, tools, and human-machine interfaces that provide improved trust, transparency in the autonomous system or provide more flexible, cognitively matched human-machine interaction and cooperation.

DESCRIPTION: Human-autonomous system interaction is frequently limited by lack of confidence and trust among the (combined) team. In order to have humans collaborate effectively with autonomous systems, improved interfaces and interaction techniques, and frameworks of interaction must be developed that allow for a common perception of the goals, constraints, resources, and other variables relevant to the team's overarching objective. Tools that allow for improved transparency into the machine's reasoning, human-machine interfaces that allow for more natural and flexible interaction and shared decision making, and information/decision frameworks that provide cognitively matched human-machine situational awareness would all support more effective and trusted human-machine teaming. Development of better measures of human trust or measures of the accuracy of shared human-machine perception would also facilitate improved teaming.

PHASE I: The first phase consists of investigating and developing novel interaction techniques and frameworks, tools, or human-autonomous system interfaces that would provide one or more of the following advantages: effective teaming through improved transparency, a natural shared human-machine perception of the problem space or operational environment, flexible and trusted shared decision making (or task allocation), or improved measures of human intent/trust/vigilance.

The Phase I deliverables should include a final Phase I report that will include the algorithms and hardware needed to implement the framework, tool, or human-machine interface. Feasibility of the proposed approach should be demonstrated through simulation or implementation.

PHASE II: Phase II shall produce and deliver fully functional, prototype software that demonstrates in a more refined and robust manner the functionality and capabilities developed in Phase I. Analysis of the performance of the combined team must be included, for example:

- A comparison of the transparency of the automated system to the human operators relative to current (i.e. baseline) systems, or a comparison of the level of human trust in the automation.
- Some reasonable measure of the improved performance afforded by the framework, tool, or interface relative to a current (baseline) system.
- Discussion of the trade-offs inherent in the novel software interface or tool with regards to human trust, efficiency of the automation, and total system performance.

The Phase II prototype software should show proof-of-concept by applying the framework, tool, or interface to a particular, relevant DoD use case.. Of particular interest would be use cases that can be generalized across domains (e.g., Underwater vehicles) or include heterogenous autonomous systems (e.g., air/ground/sea coordination).

PHASE III: DUAL USE COMMERCIALIZATION: Transition the work of phase II to a DoD development effort. Improved human-machine teaming in autonomous systems should reduce training time, increase ease of use, and improve total system performance. Autonomous systems are also in limited use in manufacturing fabrication, logistics scheduling, and remote vehicle management/operation.
Potential commercial applications of this technology include designing human-autonomous systems interfaces and interaction tools for management of complex manufacturing systems, scheduling of complex or rapid logistics processes, or trusted multi-aircraft or multi-truck vehicle system control.

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KEYWORDS: Autonomy, Perception, Collaboration, Human Machine Interface, Trust, Cooperative Control, Human-Robot Interaction.

OSD13-LD1 TITLE: <u>Deep Analytics for Data in Cyber-Physical Systems</u>

TECHNOLOGY AREAS: Information Systems

Objective: To develop and integrate automated algorithms with visual analytic tool for processing information in cyber-physical systems.

Description: As the Department of Defense increasingly emphasizes autonomous implementation of many tasks that are traditionally done by humans, it is imperative that the Tri-Services support scientific research and technology development in the domain of human-cyber-physical system collaboration. These systems are necessarily complex with intricate interacting subsystems whose formal models and the degrees of abstraction required for specification or verification of coupled components are still beyond one's grasp.

In this direction, the objective of this topic aims to tackle selected technical issues that frequently arise in the human-cyber-physical systems. Particularly, this SBIR topic focuses on the interaction between humans and information generated by cyber-physical systems. Such information can be in the form of sensor data, network data, textual data, etc. Information generated in this manner needs to be extracted, integrated, examined by humans, with background knowledge, and fed back into cyber-physical systems iteratively until some performance metrics or requirements are satisfied. This multi-stage information processing and exchange between humans and cyber-physical systems requires sophisticated algorithms and smart interactive tools working in tandem.

This topic seeks advanced algorithms that can support information extraction and integration for a wide range of data types. Advanced algorithms are also needed to process humans' instructions input from a visual interface. Finally, new algorithms are sought to support hypothesis generation and hypothesis testing through deep reasoning that is provided by cyber-physical systems, humans, or their collaborative effort.

Beside the importance of algorithms, interactive visualization should also be designed for displaying abstract information in a form comprehensible to humans, assisting deep reasoning, understanding of cause-and-effect relationships, verifying results output by cyber-physical systems, facilitating workflow management.

Algorithms, information representation, and interactive visualization designs must be based on rigorous scientific principles. In addition, novel ideas in mathematics, statistics, and computer science are highly encouraged. The performer should seek to demonstrate effective use of their proposed approaches in one of the following areas of cyber-physical systems: Combat Casualty Care/Health IT, Occupational Health and Safety for Military Operations, Dynamic Logistics.

PHASE I: Select one of the above examples of cyber-physical systems that can support a DoD mission. Develop a suite of algorithms, as mentioned in the Description section, which are needed for this domain of interest, taking into consideration of various data types. Characterize the performance of these algorithms in terms of speed, accuracy, robustness, etc. Design novel interactive visualization tool that can interface with the designed algorithms and user's input.

PHASE II: Characterize the "ease of use" and the "learnability" of the visual interface. Characterize the effectiveness of the human-cyber-physical system interaction. Develop a prototype system by integrating the tools developed in Phase I and apply them to the selected domain of application. Demonstrate effective use of the prototype and characterize its overall performance. The deliverables will include written reports, working prototype of the technology, and performance evaluation with real-world data.

PHASE III. Mature the technology developed in Phase II. The final product should have dual applications, in both military and commercial domains. In military applications, the technology can benefit Combat Casualty Care/Health IT, Occupational Health and Safety for Military Operations, or Dynamic Logistics. In the commercial sector, this technology can provide seamless integration of humans and machines or cyber-physical systems in different applications: air traffic control systems, health information technology, power grids and mass transportation systems, etc.

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KEYWORDS: Big Data, Information Extraction, Visual Analytics, Reasoning and Inference, Human-System Interaction, Cyber-Physical Systems.

OSD13-LD2 TITLE: Knowledge-aided Interface for Big Data Streams

TECHNOLOGY AREAS: Information Systems

OBJECTIVE: Develop an innovative cognitive knowledge-aided interface and supporting information processing techniques to exploit very large data streams over wide areas and autonomously highlight areas of interest for tactical decisions without a priori knowledge of the area and/or location of high value.

DESCRIPTION: Big data challenges across Department of Defense (DOD) domains are increasingly problematic for tactical level decision making. Data collections in the open source and military channels are growing at such a staggering rate that it exceeds our ability to store and manage, perform computation and analysis, and maintain data security [1, 2]. Indeed, one author refers to the inability to handle big data as the new 'helplessness age' [1], a reaction to the inability of information processing algorithms to rapidly extract key elements of information to aid decision making in time constrained environments. Architectural limitations are a major constraint to discovering knowledge from big data stores that represent complex combinations of many data types [3]. Due to the exponential increase in data, combined with the limitations in processing capability, it is unlikely that Warfighters operating in uncertain and unfamiliar cultural environments will benefit from knowledge discovery capabilities any time soon. To reduce vulnerability and risk for Warfighters from unknown threats, new and innovative approaches are needed for data collection, processing, and user interface designs. Promising approaches in this space include data streams [4], interactive exploration and hypothesis testing of data [5], and temporal segmentation of large text corpora [6].

Addressing data stream computation is recognition that tactical decisions require a very small subset of all data available in military databases and that valuable data may often be separate from the traditional hard sciences approach to persistent collection and quantitative analysis [5]. In data stream processing, data arrives in continuous, high-volume, fast and time-varying streams [4]. Clustering, classification, and association algorithms may be useful for mining data streams, but transferring results over a wireless network with limited bandwidth could prove challenging for tactical units [4].

Interactive exploration and hypothesis testing of data streams could serve to filter large amounts of information for specific tactical knowledge requirements. Frequently, Warfighters don't know the right questions to ask and have very limited opportunities to explore options for potential outcomes. Bio-inspired applications for interface design and collaboration in a visual domain could improve interface designs. Biological features that might be adapted to interfaces could include autonomy, scalability, adaptability, and robustness [7], each designed to detect data patterns, identify anomalies, and extract knowledge from enormous volumes of data. The key component of achieving success in this particular problem area is to ensure that computer and social scientists work closely together [1] in order to develop sufficiently robust algorithms with greater reliance on reasoning that allow a domain-relevant interpretation of actionable patterns of behavior and meaning for informed decision making [2].

Temporal segmentation of large text corpora may provide a method by which data may be filtered at tactical levels for rapid processing and knowledge extraction. Using text open sources (e.g., newspapers, blogs, Tweets, Facebook posts) would provide Warfighters with near-real time insight into semantic tones of localized text [6]. The potential value of this approach would be to allow users to infer a timeline of factors correlated with ideas identified from analysis of public discussion in text corpora.

The challenges with this topic are storage and management of big data, which may contribute to an inability to validate and qualify each data item. Also, careful design of systems is necessary to match user needs and the technologies used for analytics and visual display of information. In addition, accessing very large quantities of semi- or unstructured data is problematic and limited by available storage applications and hardware. Finally, user needs must be supported by computational processes, with these expressed in ways that are consistent with the larger social system in which the user operates. Frequently, user studies concentrate on the micro-system of the individual user and fail to consider the wider range of opportunities, challenges, and constraints.

The current topic seeks to address those challenges by focusing on a new and innovative data collection/storage/processing method that can reduce noise in large data while keeping relevant data streams for processing. It also will explore interactive user interface designs that allow temporal segmentation, or other useful algorithms, which should consider bio-inspired applications. Finally, placing the user within the larger social system for developing filtering and visual methods will provide a unitary perspective for knowledge discovery and dissemination.

PHASE I: Design an integrated approach for interactive exploration of big data streams that allow users to meaningfully interact with data and apply a variety of algorithmic filters designed to facilitate rapid knowledge extraction. Define requirements for developing and implementing a technique that is noticeably different from current fusion methods and that is useful for large data streams. Define a user scenario that considers a user in a tactical setting and incorporates the larger social system that bounds the knowledge extraction and dissemination process. Provide theoretically based and mathematically sound foundations for proposed approaches that incorporate social and computational science. Requirements definition must include: a description of the model components and the supporting relationships, the computational processing technique that will be used and a description of the integration mechanisms, a determination of the types and characteristics of the metrics that will be captured and used, a detailed discussion of the specific domain to be represented, and a discussion of analysis and assessment techniques to be used. Phase II plans should also be provided, to include key component technological milestones and plans for testing and validation of the proposed system and its components.

PHASE II: Produce a prototype system based on the preliminary design from Phase I. All appropriate engineering testing will be performed, and a critical design review will be performed to finalize the design. Phase II deliverables will include a working prototype of the system, specification for its development, and a demonstration and validation of the ability to both accurately represent the model of the soft information fusion and the collaborative visual analytics representation of the data.

PHASE III: This technology will have broad application in military, government, and commercial settings. Within the military and government, there is an increasing emphasis on understanding and forecasting group behaviors from social media and online social communities in foreign nations that are potentially hostile to US and Coalition interests. Currently, fusing information from these sources is extremely labor intensive and costly in terms of labor and time. Developing interactive interfaces that can explore dynamic data streams and extract knowledge rapidly will be a powerful addition to tactical decision making.

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KEYWORDS: Big data, decision making, social science theories, computer analytics, interactive display techniques, temporal data streams

OSD13-LD3 TITLE: Layered Data to Areas of Interest

TECHNOLOGY AREAS: Information Systems

OBJECTIVE: The objective of this research is to use spatial, temporal and graph analysis techniques to take very large data streams over wide areas and autonomously highlight areas of interest for a decision maker without a priori knowledge of the area and/or location of high value.

DESCRIPTION: To protect U.S. national interests and achieve the objectives of the 2010 National Security Strategy, the Joint Force will need to recalibrate its capabilities and make selective additional investments [1]. The well-publicized push to the Pacific Rim drives a need to improved mission planning over much larger areas, including some for which conventional information gathering is challenging. Improved pattern recognition capabilities enabled by spatial, temporal and graphical analysis are one way to effectively improve mission planning and execution given limited resourced.

The U.S. Marine Corp desires to improve battlespace awareness (to know the enemy and environment) through improved analysis, prediction and production [2]. Relevant raw data can usually be stored and subsequently visualized spatially, temporally or as a graph. The automated recognition of an area and/or location of high value is basically a pattern recognition problem that must be solved in the absence of a data that is naturally tied to a uniform grid. Data about remote areas can still include imagery, radar and open source which can include social and cultural information. The diversity of this data set makes the establishment of the uniform grid often required by pattern recognition algorithms challenging [3]. The extraction and preprocessing of features from raw data is also challenging due to the well-known influences of environmental, social and cultural influences on the importance of other observed features [4]. Cognitive processes and context need to be considered by location/area of interest pattern recognition algorithms. [5]

The technical challenges of this topic are as follows: 1) Select and automate the population of a feature layer; 2) Preprocess data as required to approximate a uniform grid; 3) uncover linear/ nonlinear correlations between environmental, social and cultural variables and feature importance; 4) Mature models for why/when a location/area would be of interest; 5) Mature pattern recognition algorithms that approximate human recognition and classification skills utilizing cognitive insight; 5) provide a means to visualize current and predicted states (e.g. heat maps showing locations/areas of interest given a context). Define and apply metrics to measure modeling and prediction accuracy and potential for success of products produced.

Creative solutions are desired. Data used should be relevant to potential use for product transition, such as a government agency, program of record or commercial market place. Use of open standards is encouraged to reduce costs and improve system interoperability.

PHASE I: Identify a geographic region for study and data layer design concept. Demonstrate that diverse types of data can be ported to a spatial grid structure relevant to pattern recognition. Develop features models for areas of interest and then perform a proof of concept demonstration of a pattern recognition capability. The demonstration should be conducted using open source data. Document results from analysis and tests in a technical report or paper at a selected conference. The final Phase I brief should show plans for Phase I Option 1 and Phase II.

PHASE II: Produce a prototype system that is capable of rapidly identifying locations/areas of interest based on a given context and visualizing that information as spatial heat maps with data traceability. The system should be able to automatically process data as sequential batch files or streaming data, accepting all standard raw data formats for images, maps, tracks, text and graphs. It is desired that context and pedigree of information be maintained for operator review. At this point the performer should focus on a proof-of-concept of capability of interest to transition program.

PHASE III: Produce a system capable of deployment and operational evaluation. The system should consume available operational data sets and focus on areas that are of interest to specific transition programs or commercial applications. Machine based processing steps and metadata should be accessible by operator and presented in human understandable form. The software and hardware should be modified to operate in accordance with guidelines provided by transition sponsor.

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KEYWORDS: Pattern recognition, spatial grid analysis, activity detection, data features, prediction, cognitive science

OSD13-PR1 TITLE: Direct Injection Systems for Improved Performance, Durability, and Economy

TECHNOLOGY AREAS: Air Platform

OBJECTIVE: Develop and demonstrate an advanced high pressure, heavy fuel (JP-8) injection system for UAS/UGS applications, capable of performing multiple injections per cycle.

DESCRIPTION: This effort is to develop a fast responding, light weight, direct injection system to operate within the fuel’s ignition delay time for UAS/UGS application. These systems must be applicable to engines that are 200 HP or less, either reciprocating or rotary. A technical challenge associated with the conversion of gasoline engines to heavy fuel (JP-8) is the avoidance of knock. An approach used to avoid knock is to operate within the fuel’s ignition delay time; hence to employ direct combustion chamber injection.

The challenges of the reciprocating engine are to avoid end gas knock (auto ignition occurring in the end gas after spark) and to inject the fuel very late into the cycle. The challenges for the rotary engine are atomization and the avoidance of wall quenching due to its combustion chamber shape. Delaying the injection process causes higher pressure rise rates which can exceed the engine's design capabilities. An injection system that offers fast response and multiple injections per cycle may alleviate excessive pressure rise and the avoidance of knock.

Good combustion control eliminates many durability issues from overloading, shock, and combustion deposits. The shape of the combustion trace can be tailored through multiple injection pulses and combustion deposits can be controlled with better atomization and fuel patterns. Hence an injection system that offers fine atomization, fast response, and multiple injections per cycle is needed. System components are to include injectors, high pressure supply pump (1000 bar min), feed pump and controller with harness.

PHASE I: Develop an improved fuel injector capable of performing multiple injections per cycle, operating at high pressures (above 1000 bar) and producing droplet sizes finer than 10 to 15 microns. These injectors will result in improvements to the direct injection process for reciprocating and rotary UAS engines. Analytical predictions of spray pattern through Computational Fluid Dynamics (CFD) and 3-D computations are desired. Bench tests of fuel system components operating at designed pressures and quantification of injection spray pattern are desired. The fuel injection system should have the capability to perform multiple injections per cycle and at engine operating speeds up to 6,000 rpm.

PHASE II: Demonstrate and validate the performance of the Phase I technology in a laboratory environment on a representative engine. Engines should be of size and power appropriate for the Predator and Shadow-200 UAV class. Further analytical modeling and spray tests must supplement engine testing. The avoidance of knock while operating on JP-8 and delivering equivalent power is the desired outcome.

PHASE III DUAL USE APPLICATIONS:
Military Application: This technology is applicable to Air Force, Navy, and Army small, heavy fuel engines currently under development. The conversion and design of heavy fuel engines necessitates high responding injectors capable of fine atomization, fast response, and multiple injections per cycle. These injectors have the potential to be incorporated into engines such as the USAF's Predator-Rotax 914 and the US Army's Shadow-200 to minimize damaging effects of knock and to avoid wall quenching through fine atomization.
Commercial Application: This technology has additional transition opportunities in the commercial sector for ground vehicles or civil UAVs. Companies could incorporate the injectors, high pressure supply pump, feed pump and controller with harness to optimize the fuel injection associated with the engines. This could lead to cleaner combustion that could greatly increase the life of the engine. Further, advanced direct injections systems have the potential to reduce specific fuel consumption.

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KEYWORDS: Atomization, emulsification, JP-8, Knock, ignition delay time

OSD13-PR2 TITLE: Advanced Sealing Concepts for Small Heavy-fuel, Remotely Piloted Aircraft Propulsion Systems

TECHNOLOGY AREAS: Air Platform

OBJECTIVE: Develop sealing technologies for heavy fuel engines for Remotely Piloted Aircraft (RPA). The technology should address sealing in engine classes of reciprocating and rotary engines for improved durability.

DESCRIPTION: Shortfalls with existing RPA systems include durability issues associated with engine seals. Two key RPA systems in the DoD inventory are the USAF's Predator and US Army's Shadow-200. Both of these systems have seal/wear issues. In the reciprocating engine - it's the piston - cylinder interface, and in the rotary engine it's the rotor - housing interface. Sealing systems which have high wear resistance, light weight, and have high thermal stability are sought.

Future, advanced engines for small RPA’s are expected to make use of new materials, such as: ceramics, advanced metallics, composites, and other lightweight materials. This will require the development of new sealing technologies that are compatible with the materials used in these advanced engines. Such efforts are in the initial stages of development, exemplified by a program to replace the metallic rotor in a rotary (Wankel) engine, with a silicon nitride rotor. Other engine developments such as the Nutating engine and Migrating Combustion Chamber (MCC) are under development and are developing new lightweight materials to optimize the combustion systems in these engines. Considerations are to examine an array of tribologic factors, such as surface hardness, surface coating, and self-lubrication.

Improvements are sought to address the wear/durability issues; specifically for the apex seal/rotor/housing of the rotary engine, piston/ring/cylinder for reciprocating engines, and other sealing technologies for innovative engines. Furthermore, these wear/durability issues must address engines running on heavy fuel (JP-8 and/or diesel fuel) and have such characteristics to increase the time between overhauls.

PHASE I: Determine common combustion seal material issues between piston ring/cylinder interface for reciprocating engines, apex seal/trochoid housing for rotary engines, and other sealing technologies for innovative engines. Items to be identified include: relative speed between sealing surfaces, loading, estimate of friction coefficients and lubrication. Develop concepts and material combinations to address these issues. Activities included in this phase consist of analytical modeling and small scale coupon testing to show proof of concept.

PHASE II: The Phase II effort would consist of selecting material combinations from those identified in Phase I and conducting controlled bench tests to evaluate the combinations for each different engine applications in terms of: relative surface speed, loading between seal face and housing/cylinder, level of lubrication, and temperature at the sealing surface. These material and sealing designs are to be demonstrated in representative UAV engines.

PHASE III DUAL USE APPLICATIONS:
Military Application: Advanced sealing concepts for small, heavy fuel engines are applicable to the Air Force, Navy, and Army forces. Each service of the DoD operates RPAs that are powered with small engines. Incorporating advanced sealing concepts into RPAs such as the USAF’s Predator-Rotax 914 engine and the US Army’s Shadow-200 has the potential to increase engine efficiencies, reliability, and durability.
Commercial Application: This technology has additional transition opportunities in the commercial sector for small engines, ground vehicles and equipment, and lightweight power generation. Incorporating advanced sealing technologies into commercial engines has the capability for companies to change material interfaces to increase engine efficiencies. Furthermore, this technology is applicable to hybrid applications.

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OSD13-PR3 TITLE: Advanced Thermal Management Systems for Improved UAV Engine Durability/Performance

TECHNOLOGY AREAS: Air Platform

OBJECTIVE: To develop, and demonstrate improvements in cooling capability of propulsion systems currently in use on unmanned aerial vehicles (UAV); to show a 20% reduction in cooling efficiency.

DESCRIPTION: Two of the most popular UAVs used in the US are the US Air Force's Predator, and the US Army's Shadow 200. The US Air Force Predator is classified as a medium altitude, long endurance UAV and is powered by a 100 HP 4-cylinder piston engine. The US Army's Shadow 200 is a tactical UAV and is powered by a 38 HP rotary engine. Both of these propulsion systems suffer durability issues which can be linked to undesirable heat transfer within the engine. Moreover, desired increases in engine power or improvements in engine efficiency are limited by thermal loading in the engine.

This topic will focus on the development of improved cooling methodologies for the above mentioned engines. The piston engine relies primarily on liquids as the cooling medium (oil and engine coolant) while the rotary engine rejects heat directly to the airstream. A solution is sought to better manage internal heat transfer which can be applied to either engine. Proposed solutions should be consistent with the desire to increase engine power, improve engine efficiency, and be compatible with heavy fuels. As the engine is to be used in flight, the following constraints apply: 1) minimal or no increase in the frontal area. 2) minimal or no increase to the installed weight of the propulsion assembly.

PHASE I: Define and determine innovative technologies that will result in improvements to the engine cooling with minimal frontal area/weight impact. Demonstrate the feasibility of the approach through a detailed design. Identify the impact to the engine installation in terms of weight and bulk. Estimate improvements to the engine which may be realized by incorporation of the technology, specifically increases in power output (brake mean effective pressure, BMEP), improvements in efficiency (brake specific fuel consumption, BSFC), or durability (time between overhaul, TBO). A demonstration of hardware or fabrication/test of key components is desired.

PHASE II: Demonstrate and validate performance improvements based on the Phase I technology on representative engine. Fabricate and bench test (as appropriate) prototype hardware or modifications. Conduct baseline testing on an in-service UAV engine incorporating the new technology. Refine the design and develop a plan leading to production-ready hardware.

PHASE III DUAL USE APPLICATIONS:
Military Application: Advanced thermal management systems are applicable to the Air Force, Navy, and Army. An increase in thermal management of engines could lead to increase life of engine components, and, thus, possibly a large cost savings per engine. This could be directly applicable to heavy fuel engines currently under development, such as the USAF's Predator-Rotax 914 engine and the US Army's Shadow-200 using the UEL AR741.
Commercial Application: Current commercial applications aim for an increase in engine power, and an increase in engine power leads to an increase in heat transfer to engine components. Advanced thermal management systems offer the ability to minimize heat transfer to engine components. Further, this topic will incorporate thermal systems without a large increase in engine weight or size, which can be made directly applicable to the commercial market.

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KEYWORDS: heat transfer, high volume oil flow, intercoolers

OSD13-PR4 TITLE: Advanced Durability Systems for UAS Propulsion

TECHNOLOGY AREAS: Air Platform

OBJECTIVE: Improve UAS engine durability by applying advanced designs/materials for bearing, housing, and rotating components/systems.

DESCRIPTION: UAS propulsion systems currently suffer from durability issues resulting in frequent overhauls. Incorporating advanced durability systems could lead to longer durations between engine overhaul times and increased engine life, resulting in a larger payback per UAV investment. These advanced durability systems can be applied to bearings, rotating components and static components in order to increase the life and times between overhauls.

Bearings are an essential part of all UAV systems. As technologies continue to advance in current air vehicles, more demands are being made on bearing capability. With an increase in the demand of bearing capacity comes an increased risk of bearing fatigue and wear caused by heavier loading, inadequate/unsuitable lubrication and overheating. Future engine improvements need to incorporate advanced bearing designs and concepts to increase bearing durability and, thus, increase time between overhaul for UAV systems. Examples of advanced durability concepts include but are not limited to ceramic ball bearings and fuel lubricated bearings. Ceramic ball bearings have advantages of higher operating speeds, increased stiffness, lower friction, and less heat generation. The incorporation of ceramic bearings into UAV systems has the capability to reduce wear on the bearings through an increase in engine durability. Further, fuel (JP-8) lubricated bearings offer substantial benefits resulting from the elimination of the conventional recirculating lubrication system.

Metal matrix composites (MMC) offer added strength and durability that can be incorporated in both static components such as engine housings and rotating components, where ceramic matrix composites (CMC) also offer benefits with respect to heat transfer in the engine housing and reduction in engine weight. The benefits offered by composite and ceramic materials are high strength-to-weight ratios, high temperature tolerance, low coefficients of thermal expansion, low coefficients of friction, and favorable lubrication properties. The high strength-to-weight ratio is a favorable property for engine components as it reduces the rotational mass of the engine and increases the specific power. The low coefficients of expansion of these materials allow tighter tolerances between moving and static components of the engines, which could lead to increased durability and longer engine life. Applications for this technology include engine liners, coatings for combustion surfaces, bearing cages and housings, rotating shafts, pistons, and rotors.

PHASE I: Define and determine advanced durability systems that can be incorporated into bearings, rotating components, and static components of engines to increase durability of current UAV propulsion systems. This may include but is not limited to ceramics, metal matrix composites, ceramic matrix composites, fuel (JP-8) lubricated bearings, and ceramic ball bearings. Applications should be oriented to UAV propulsion systems with the intent to increase engine durability and reliability upon implementation of these advanced durability concepts. Present day durability parameter for tactical UAV propulsion is $150/hr – a 20% improvement is sought.

PHASE II: Apply the concepts researched and developed in Phase I to a current UAV propulsion system. The advanced durability system should be incorporated in a relevant UAV engine and demonstrated in a laboratory environment. Small scale testing of these engines should show increased durability upon the implementation of advanced durability systems.

PHASE III DUAL USE APPLICATIONS:
Military Application: This technology is applicable to Air Force, Navy, and Army UAV systems. By implementing advanced durability systems such as ceramic bearings, fuel lubricated bearings, and composite structures, the durability of each UAV can be greatly increased, increasing overhaul time and operation for each aircraft. This has

significant cost and efficiency savings for the DoD.
Commercial Application: This technology has additional transition opportunities in the commercial sector. Performance is a key factor in the commercial industry and with an increase in performance of small engines comes durability issues such as fatigue and overheating of engine components. By applying advanced durability systems to the rotating components, static components, and bearings of commercial engines, performance can be greatly increased.

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KEYWORDS: ceramics, fuel lubrication, durability, UAV systems

OSD13-PR5 TITLE: Improved Turbo/Superchargers for UAS/UGS Application

TECHNOLOGY AREAS: Air Platform

OBJECTIVE: Demonstrate an advanced forced induction system for UAS/UGS applications in the 50 to 150 HP range.

DESCRIPTION: The benefits of greater power and efficiency are offered by using turbochargers and superchargers for small UAS propulsion systems which including rotary, piston, and other developing engines. Present day UASs suffer performance losses upon takeoff and at altitude. Therefore, the need for improved, light weight turbo and superchargers which eliminate the use of oil lubrication for the bearing system is needed. Furthermore, current UAS systems are experiencing durability issues with turbochargers due to oil coking. Light weight forced induction systems with improved bearing and lubrication circuits are sought for the 50 to 150 HP UAS class.

The bearing systems in turbochargers and superchargers are normally oil-fed from the engine oiling system. The bearings in these systems run in an extremely harsh environment and are subjected to axial, radial and thermal loads that limit the life of the turbocharger system and can cause failures during important mission sorties. The elimination of the pressurized oil bearing system would greatly enhance reliability and durability and decreases losses of aircraft that are employing turbochargers and superchargers. There are a number of engines that could use turbocharger technology but some do not have pressurized oiling systems. Even systems that have pressurized oiling systems suffer from pumping losses due to the oiling system having to supply oil to the turbocharger and supercharger. Additionally, when operating at high angles of attack, the pressurized oil systems may not provide adequate lubrication for the bearing systems. Having a system that optimizes the ability to place the turbocharger or supercharger in airframe positions that are not possible with a pressurized oiling system is a must.

Lastly, the forced induction system should be light weight and reliable. The weight should less than 5% of the overall engine system.

PHASE I: Develop a design concept for turbo/supercharger systems that are light weight, durable, and self-lubricated including bearing and material selection. The design should consider forced induction loading, thermal loads, and operating speeds. Reliability and durability performance parameters should be part of the analysis and potential bench top testing of candidate systems should be performed in Phase I.

PHASE II: This phase builds off the progress made in Phase I to incorporate the bearing system in an advanced turbo/supercharger and demonstrate it in an operational UAS propulsion system. This will include analytical modeling, the appropriate bench testing for system integration, and an engine demonstration.

PHASE III DUAL USE APPLICATIONS:
Military Application: Advanced turbocharger/supercharger technologies are directly applicable to the Army, Air Force, and Navy. This advanced technology allows for an increase in power for small engine classes, leading to more mission capability. It also allows turbochargers to be incorporated into current systems without pressurized oil systems that previously would not be able to increase power through a conventional turbocharger system.
Commercial Application: The advanced turbocharger/supercharger technology is applicable to commercial applications. Lightweight turbochargers can be incorporated into small engines to increase power without significantly effecting engine size and weight. Further, the elimination of the pressurized oil bearing system on turbochargers would allow for enhanced reliability and durability on commercial engines.

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