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N20A-T001 TITLE: Optimized Energy-Attenuating Seat Design for Ground Vehicles

TECHNOLOGY AREA(S): Biomedical

ACQUISITION PROGRAM: Program Executive Office (PEO) Land Systems, (FNC Armored Reconnaissance Vehicle)

The technology within this topic is restricted under the International Traffic in Arms Regulation (ITAR), 22 CFR Parts 120-130, which controls the export and import of defense-related material and services, including export of sensitive technical data, or the Export Administration Regulation (EAR), 15 CFR Parts 730-774, which controls dual use items. Offerors must disclose any proposed use of foreign nationals (FNs), their country(ies) of origin, the type of visa or work permit possessed, and the statement of work (SOW) tasks intended for accomplishment by the FN(s) in accordance with section 3.5 of the Announcement. Offerors are advised foreign nationals proposed to perform on this topic may be restricted due to the technical data under US Export Control Laws.

OBJECTIVE: Quantify how differences in warfighter pelvis geometry and seated posture affect the injuries they receive in vehicle blast events. Use this knowledge to optimize energy-attenuating seat design.

DESCRIPTION: Effectively informing energy-attenuating seat design for vehicle accelerative loading events requires an understanding of how changes in occupant size, gender, posture, and anthropometry affect how injuries present. It also requires a thorough understanding of pelvis and lumbar fractures in addition to potential ligament, organ, and vascular damage.

Ground vehicle underbody blast events that occurred during Operation Iraqi Freedom and Operation Enduring Freedom resulted in many mounted warfighters sustaining injuries to their pelvis and lumbar spine structures [Ref 5]. As a result, many ground vehicle programs have incorporated blast-mitigation technologies within their vehicles to try to protect warfighters against such injuries. However, current blast mitigation technologies are typically only designed to protect a 50th percentile male occupant. Since military vehicle occupants encompass a wide range of anthropometric variability, there is a high likelihood that many are not being protected with the current technologies.

Accurately predicting the occurrence of injuries and identifying how they present are important steps in designing effective blast mitigation. However, this is quite challenging across the wide spectrum of warfighter anthropometries and seated postures, since variability in anthropometry and seat posture can affect how injuries occur. As an example, pelvis injuries associated with vertical loading present differently depending on the occupant's bone strength. For those with weaker bones, the injuries tend to present in pubic rami or sacral fractures [Ref 3]. For those with stronger bones, the injuries tend to present in ligamentous injuries. Both cases can lead to vertical and rotational instabilities in the pelvis, which can result in quite severe injuries. Spinal fractures are also prevalent in cases where the pelvis is being loaded vertically. Accelerative events that occur over a shorter duration typically result in injuries to the pelvis, whereas longer duration accelerative events often result in spinal fractures instead [Ref 5].

Energy-attenuating seats for ground vehicles are typically designed to protect a 50th percentile male [Ref 4] during a five meter per second to eight meter per second vertical drop with pulse durations of approximately 6 milliseconds [Ref 1]. While the energy-attenuation might perform well in those specific conditions, it may experience issues with occupants who are not 50th percentile males or whose posture differs from the test condition. In one study, the energy-attenuation device did not engage for a 5th percentile female occupant [Ref 4], resulting in an injury.

The Phase I effort will not require access to classified information. If need be, data of the same level of complexity as secured data will be provided to support Phase I work. The Phase II effort will likely require secure access, and the contractor will need to be prepared for personnel and facility certification for secure access.

Work produced in Phase II may become classified. Note: The prospective contractor(s) must be U.S. owned and operated with no foreign influence as defined by DoD 5220.22-M, National Industrial Security Program Operating Manual, unless acceptable mitigating procedures can and have been implemented and approved by the Defense Security Service (DSS). The selected contractor and/or subcontractor must be able to acquire and maintain a secret level facility and Personnel Security Clearances, in order to perform on advanced phases of this project as set forth by DSS and Marine Corps Systems Command in order to gain access to classified information pertaining to the national defense of the United States and its allies; this will be an inherent requirement. The selected company will be required to safeguard classified material IAW DoD 5220.22-M during the advanced phases of this contract.

PHASE I: 1) Investigate how anthropometric variability and changes in seated posture affect pelvis and lumbar spine injury. 2) Develop capability to accurately predict pelvis injury, lumbar spine injury, femur fracture, and soft tissue injuries of warfighters. 3) Demonstrate an initial concept design to improve energy-attenuating devices for seats based on the results of 1) and 2). Provide a Phase II development plan with performance goals and key technical milestones that will address technical risk reduction.

PHASE II: Establish and deliver injury metrics developed through experimentation and/or modeling and simulation that define how anthropometric variability and changes in seated posture affect pelvis and lumbar spine injuries. Develop and deliver a tool to accurately predict pelvis and lumbar spine injuries of warfighters. Quantitatively demonstrate that the injury metrics are biofidelic and that the injury prediction tool correctly captures injury prediction based on the Marine Corps requirements described above. Mature the design of an energy attenuating device, build and deliver a prototype of the energy attenuating device, and develop and deliver a finite element model of the energy attenuating device with material and geometry information. Demonstrate through test and/or simulation that the energy attenuating device meets the requirements described above. Prepare a Phase III development plan to transition the technology to Marine Corps use.

It is probable that the work under this effort will be classified under Phase II (see Description section for details).

PHASE III DUAL USE APPLICATIONS: Investigate how anthropometric variability and positioning differences inform injuries to other body regions. Expand the injury metrics and injury prediction tools to encompass injuries beyond the pelvis and lumbar spine. In addition, develop and test additional blast mitigation technologies. Integrate the blast mitigation technologies into seats and vehicles.

The technologies developed under this STTR topic can be marketed to military ground vehicle designers and manufacturers, the automotive industry, and the aerospace industry.

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KEYWORDS: Energy-Attenuating Devices; Injury Prediction; Injury Metrics; Pelvis; Pelvic Injuries; Lumbar Spine Injuries; Seat Design; Anthropometric Variability

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Questions may also be submitted through DOD SBIR/STTR SITIS website.

N20A-T002 TITLE: Machine Learning Tools to Optimize Metal Additive Manufacturing Process Parameters to Enhance Fatigue Performance of Aircraft Components

TECHNOLOGY AREA(S): Air Platform, Materials/Processes

ACQUISITION PROGRAM: JSF Joint Strike Fighter

OBJECTIVE: Develop an advanced machine learning (ML) tool capable of optimizing process parameters for metal laser powder-based additively manufactured components to achieve enhanced fatigue performance for aircraft components.

DESCRIPTION: Laser powder bed and powder feed additive manufacturing (AM) technologies have proven to produce complicated parts from high-performance alloys such as titanium, Inconel, and tool steel [Ref 1]. Many processes are currently able to consistently produce intricate geometries and meet standard geometric tolerances. However, achieving predictable part performance, including static (e.g., strength) and dynamic (e.g., high cycle and low cycle fatigue) behaviors remains a significant challenge. In order to attain satisfactory part performance, pre- and post-processing parameters are tuned using expensive trial and error approaches. Perhaps the use of various sensors integrated with simulation and modeling tools that leverage data analytics, data fusion, and machine learning (ML) techniques may improve fatigue performance of AM parts, potentially without any post-processing required.

Due to the multi-scale and multi-physics phenomena associated with processing and post processing of various metallic alloys, it is necessary to adopt an integrated computational materials engineering (ICME) framework [Ref 2] for efficient linkages between processing and performance. Furthermore, the addition of ML methodologies and data-fusion methods should provide increased throughput and fidelity in linking AM process parameters to fatigue performance under various loading conditions.

ML involves the scientific application of computational models that can predict systemic performance using data representing input-output tuples encapsulated in a computer system [Refs 3-6]. A crucial element of ML is that the performance of a ML system can progressively use available sensor data to improve a specific system performance prediction. Thus, this topic seeks novel ML methodologies and techniques for laser powder-based AM processes (e.g., laser powder bed fusion, direct energy deposition) to yield desired aircraft part fatigue performance.

PHASE I: Develop an initial computational concept for a ML ICME-based toolset for a laser powder metal AM process under the assumption of in-situ and/or ex-situ sensor data to link AM process parameters and/or state variables to the fatigue performance of the part. Ensure that the concept methodology demonstrates both its ability for sensor fusion and its ability to learn from trial runs to predict the final part geometry, associated material properties, and final part performance. Demonstrate the feasibility of the methodology using actual AM coupons, testing (e.g., ASTM E466, ASTM E606) [Refs 7, 8], and analyses for a single material. The computational prototype of the proposed advanced ML ICME tool should have the potential for development into a full-scale ML ICME system for integrating with AM machines to enable designer to optimize fatigue life in Phase II. The Phase I effort will include prototype plans to be developed under Phase II.

PHASE II: Fully develop, verify, and validate a prototype ML system for a laser powder-based metal AM process to perform geometry control and material property control during AM processing. Demonstrate its ability to manufacture aircraft components with complex geometry and tailored performance using additional metal alloys.

PHASE III DUAL USE APPLICATIONS: Further develop and refine an advanced ML ICME system for various powder-based AM processes to fabricate specific naval aircraft components for integration into the Fleet. Conduct final component-level testing to demonstrate the geometry and material property control of AM components meeting the Navy’s specifications.

The process will be directly applicable to a wide range of AM process applications due to the high amount of anticipated AM part usage in the commercial/private aerospace industry. The proposed toolset will allow the aerospace industry to apply the benefits of AM technology to many critical aircraft components.

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https://www.astm.org/Standards/E606

KEYWORDS: Machine Learning; ML; Sensor Fusion, Fatigue; Metal Additive Manufacturing; AM; Laser Powder Bed Fusion; Powder Feed; ICME; Material Property Control

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Questions may also be submitted through DOD SBIR/STTR SITIS website.

N20A-T003 TITLE: Fully Automated Quantum Cascade Laser Design Aided by Machine Learning with up to 100X Design Cycle Time Reduction

TECHNOLOGY AREA(S): Air Platform, Electronics

ACQUISITION PROGRAM: PMA264 Air ASW Systems

OBJECTIVE: Develop a fully automated Quantum Cascade Laser (QCL) design process by using neural networks and machine learning (ML) algorithms that will result in up to 100 times reduction in design cycle time compared to the conventional "manual" QCL design process [Ref 1].

DESCRIPTION: The active region of a QCL consists of many (typically 20-50) repeated stages of superlattice (SL) material. The highest-performance QCLs operating in the mid-infrared spectral region (approximately 4.8 micron) utilize an indium phosphide (InP) substrate and have active regions wherein each stage consists of 10s of ultrathin layers of indium gallium arsenide (InGaAs) quantum wells and aluminum indium arsenide (AlInAs) barriers. The device performance metrics (such as emission wavelength, threshold-current density, slope efficiency, and their temperature dependence) are closely tied to the quantum-confined state energies and their electronic wave-function spatial distributions within the active region, which in turn are determined by the specific layered structure (i.e., layer thicknesses and compositions). The complexity of the layered structure generally requires a time-consuming iterative process between experiment and design optimization to achieve the highest device performance, which adds substantial cost to QCL manufacturing. Automated optimization algorithms [Ref 1] applied to QCL design could both greatly reduce the time (and cost) required to develop new QCL devices with specified performance characteristics and potentially lead to new insights into QCL design.

The current QCL design process generally involves a human in the loop - even for a single iteration. The function performed by the human is to identify specific features in the design and determine whether a certain performance metric can be achieved. Emerging data-driven automated optimization algorithms could potentially address the difficulties facing QCL design.

As the QCL's structural complexity grows, the design processes become more challenging. With conventional design approaches, based on computational optimization, one typically starts with a prior design and computes the performance, compared to the target response. The gradient of structural change in layers and compositions is calculated and applied to the design. This process, performed iteratively, often takes hundreds of iterations before a design is found that meets the design criteria. As an alternative, the data-driven approach is rapidly emerging where deep neural networks are used for inverse device design. A large data set of existing designs and corresponding performances can be used to train artificial neural networks so that the networks can develop intuitive connections between QCL designs and their performances. After training, the neural network can accomplish a design goal in hours instead of weeks as compared to the conventional approach. Such an approach has been used previously in photonic structures [Ref 2], where neural networks successfully model the wave dynamics in the Maxwell's equations.

Demonstrate and deliver a single-mode QCL prototype that is designed using the algorithm(s). The specifications of the QCL for this design algorithm demonstration are: > 15 W continuous wave output power at room temperature; M2 no more than 1.5 in both the fast and slow axes; laser emission in the spectral range between 4.6 to 5.0 micrometers; and no unexpected and undesirable beam steering effect as the QCL drive current is increased. Furthermore, the contractor is required to deliver the fully automated QCL design algorithms with complete and detailed user manual and documentations.

PHASE I: Develop a methodology for implementing the training plan for neural network-based QCL design optimization without human intervention. Establish performance metrics, including but not limited to, output power, beam quality, wall-plug efficiency, and thermal impedance, etc. The design verification plan for the algorithms will be implemented in Phase II. The Phase I effort will include prototype plans to be developed in Phase II.

PHASE II: Demonstrate fully automated QCL design algorithms using ML methodology. Perform experimental verification of the generated designs by demonstrating that the QCL performance metrics are met with less than +/- 2% variations from the target performance specifications. Demonstrate and deliver a single-mode QCL prototype that meets the design specifications. Deliver the fully automated QCL design algorithms with complete and detailed user manual and documentations. Benchmark the design cycle time using the algorithm aided by ML against the conventional method without using ML, and verify the cycle time reduction.

PHASE III DUAL USE APPLICATIONS: Test and finalize the technology based on the design and simulation results developed during Phase II. Transition the design algorithm for DoD applications in the areas of Directed Infrared countermeasures, advanced chemicals sensors, and Laser Detection and Ranging. Commercialize the design algorithm based on ML for law enforcement, marine navigation, commercial aviation enhanced vision, medical applications, and industrial manufacturing processing.

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KEYWORDS: Mid-Infrared; Quantum Cascade Lasers; Infrared Countermeasures; Cycle Time Reduction; Machine Learning; Design Algorithm; ML; QCL

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Questions may also be submitted through DOD SBIR/STTR SITIS website.

N20A-T004 TITLE: Hexahedral Dominant Auto-Mesh Generator

TECHNOLOGY AREA(S): Air Platform, Ground/Sea Vehicles, Weapons

ACQUISITION PROGRAM: NAE Chief Technology Office

OBJECTIVE: Develop an automated interactive mesh generator using predominately Hexahedral Finite Elements to support finite element analysis of naval aviation structural components and weapons systems.

DESCRIPTION: The U.S. Navy is accelerating its development of solutions to meet Fleet needs. As part of this urgent need, this STTR topic provides the potential to develop several advantages to the U.S. Navy. First, the use of hexahedral elements in finite element processing is far more efficient than tetrahedral elements, providing more accurate solutions, faster. Second, the use of an automated hexahedral dominant mesh generator will decrease the time spent meshing and speed the overall development of a solution. Currently, automated mesh generators use tetrahedral elements for finite element analysis. This approach is computationally intensive, because, in order to increase accuracy in the current system, there is a need for more tetrahedral elements resulting in increased hardware requirements or longer meshing and solution times.

Much of today's solid finite element analysis is performed with tetrahedral elements. Tetrahedral elements, poorly formulated mathematically, require a high element density to obtain answers to conform to classical analysis and benchmark solutions. Using large numbers of finite elements increases the computational burden on the computer by n2 for a fully stored stiffness matrix. Hexahedral elements are well-formulated showing superior performance in bending and torsion [Ref. 1]. Fewer hexahedral elements would be needed to achieve the same level of accuracy as a model built with tetrahedral elements. A hexahedral automated mesh generation requires specific geometric conditions.

A software is sought to analyze the geometry and create hexahedral mapable domains, with optional user interaction. The optional interaction should include (but not be limited to) providing options to the user to subdivide the geometry, optimize the number of hexahedral elements, and where necessary, use other elements to create a complete mesh for the user to apply boundary conditions. A graphical user interface (GUI) must allow for user inputs for variable mesh density/element size, type of elements, order of elements, and enforcement of topology. Ideally, the software would provide an interactive environment for the user to create the mesh and geometric conditions desired before applying boundary conditions. The software should be able to run on most major operating systems; Windows 10 is preferred. Software should be able to run on machine with 4gigabytes of random access memory using Intel i5 or equivalent central processing units (CPU). Inputs to the software should include, but not be limited to, generic geometry formats (e.g., Standard for the Exchange of Product model data (STEP), Initial Graphics Exchange Specification (IGES), Parasolids, ACIS, and Stereolithography (STL)). Outputs from the software should be compatible with major pre-processing software packages (e.g., FeMap, Patran, Hypermesh). This output should include NASA Structural Analysis (NASTRAN) compatibility with the option to be human readable.

PHASE I: Design a geometric decomposition algorithm on basic shapes. Basic shapes include spheres, cones, annular rings, plates with circular holes in them, and plates with "flagpoles" extending from them. Holes and like interior features should have elements feature aligned at their interior and in an annular ring around them.

Demonstrate the feasibility of the algorithm. Ensure that the software design creates the mesh using predominantly high-quality feature-aligned hexahedral elements, paying particular attention to the exterior boundary, using transition and tetrahedral elements to accommodate the remainder of the shape(s) and result in a fully meshed component. A feature-aligned element has a face parallel to the local external boundary of the geometric entity containing it, and adjacent faces that are as perpendicular to that face as is allowable by the geometric definition of that component. For example, not all faces can be orthogonal and perpendicular to a sharp corner such as the tip of a cone.

Quality metrics should be as defined in Reference 4, with the addition that all faces of the hex shall be mapable to a regular quadrilateral, i.e., no twisted or degenerate faces, no "bow-tie" faces.

Use the metrics for hexahedral elements as summarized in Reference 4.

The Phase I effort will include prototype plans to be developed under the Phase II.

PHASE II: Fully develop and demonstrate capability by importing various formats of computer-aided drawing (CAD) data to include, but not be limited to, STEP, IGES, Parasolid, STL, and ACIS. Show the geometric decomposition algorithm on Navy-provided CAD data. Develop the GUI to allow for geometric editing of the part to support hexahedral elements, provide optimal solutions, and allow users to mesh components manually.

PHASE III DUAL USE APPLICATIONS: Perform final development and testing, and demonstrate usage with other Finite Element Pre-processing software packages. Import finalized mesh for preprocessing with boundary/initial conditions.

Using hexahedral meshing is one of the most mathematically efficient methods of discretizing geometry. Automotive, Aerospace, Nuclear, and Consumer Electronic industries will benefit from the following:
Improved solution run times/faster delivery of products.
Improved efficiency: use of CPUs, company's tech refresh cycle can be less frequent.
Improved efficiency: use of CPUs, company's overall power consumption will decrease.

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KEYWORDS: Hexahedral Meshing; Finite Element; Automated; CAD; Preprocessing; Computational Efficiency

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Questions may also be submitted through DOD SBIR/STTR SITIS website.

N20A-T005 TITLE: Quantum Optical Semiconductor Chip and its Application to Quantum Communication

TECHNOLOGY AREA(S): Air Platform, Electronics, Information Systems

ACQUISITION PROGRAM: JSF Joint Strike Fighter

OBJECTIVE: Develop a quantum optical semiconductor chip and demonstrate its application to efficient photonic entanglement, efficient logic gates such as Hadamard and CNOT, and quantum communication protocols through fiber optical channels.

DESCRIPTION: Current quantum chips utilize Superconducting Quantum Interference Device (SQUID) technology, which operates under very low cryogenic temperatures of a few degrees above absolute zero. Creating such a low temperature environment is costly and difficult, making this technology less suitable for many applications. One alternative to superconductors is an optical-based technology that can operate in room temperature where expensive refrigeration is not required. Recently, the Air Force Research Laboratory (AFRL) demonstrated a quantum communication protocol called “teleportation” [Ref 1] via open-air laser using optical apparatus at room temperature. While this technology seems to be a promising alternative to the current SQUID-based technology, creating such an optical apparatus presents its own challenges and requires a room space because presently optical components are much bulkier than their silicon counterparts in SQUID. Therefore, the miniaturization of such an optical apparatus into a semiconductor chip would be hugely beneficial. With this photonic silicon chip, basic logic gates such as Hadamard and CNOT (Controlled NOT) could be built and the teleportation protocol could be performed through fiber optical channels. Different approaches can be employed for the realization of this photonic chip, such as discrete variable (qubit), continuous variable (wave packet), or a hybrid of these. If successful, this would lay the groundwork for more practical access to quantum technology (including quantum communication and distributed quantum computing) and would further enable rapid development of quantum technology in general.

Below are some of the challenges.
A) Single photon source - the goal is to generate indistinguishable photons on demand.
B) Entanglement - on-demand photonic entanglement [Ref 2] plays a crucial role in quantum information protocols. Therefore, a method for preparing photonic entangled states on demand for reliable quantum information processing needs to be developed. A new diagnostic method developed recently was to detect quantum entanglement experimentally [Ref 3].
C) Logic Gates – design appropriate waveguides to play a role in quantum logic gates.

Efficiencies for a single photon generation, on-demand photonic entanglement, and performance of logic gates are figures of merit for this effort.

Proof-of-principle on-chip demonstration of all the above requirements will be evaluated. Develop quantum optical semiconductor chips and demonstrate one of the simplest quantum information protocols, “teleportation”, based on the most essential quantum features: superposition and entanglement that are implemented by Hadamard and CNOT gates respectively.

PHASE I: Design and develop a solution for efficient entanglement and basic logic gates on photonic chips. Demonstrate feasibility of a concept. The Phase I effort will include prototype plans to be developed under Phase II.

PHASE II: Demonstrate efficient logic gates such as Hadamard and CNOT and improve entanglement efficiency. Develop and demonstrate a prototype and aid government personnel to evaluate the performance of the prototype in a laboratory. Demonstrate quantum communication protocols such as super dense coding and teleportation through fiber optical channels. Deliver a prototype and help Government personnel to evaluate the performance of the prototype in a laboratory.

PHASE III DUAL USE APPLICATIONS: Finalize and transition technology into use for Navy systems. Commercialize quantum communication and quantum sensing. The desired technology is based on quantum silicon photonics; therefore, semiconductor chipmakers can easily adapt the technology to their existing manufacturing frameworks. Just like graphics processing units (GPUs) are getting popular, quantum-processing units (QPUs) can be developed and used with central processing units (CPUs) in the future.

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KEYWORDS: Quantum Optical Semiconductor; Photonic Entanglement; Quantum Logic Gates; Quantum Sensors; Quantum Communication; Quantum

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N20A-T006 TITLE: High Efficiency Propeller for Small Unmanned X Systems (UxS)

TECHNOLOGY AREA(S): Air Platform, Ground/Sea Vehicles, Materials/Processes

ACQUISITION PROGRAM: PMA264 Air ASW Systems

The technology within this topic is restricted under the International Traffic in Arms Regulation (ITAR), 22 CFR Parts 120-130, which controls the export and import of defense-related material and services, including export of sensitive technical data, or the Export Administration Regulation (EAR), 15 CFR Parts 730-774, which controls dual use items. Offerors must disclose any proposed use of foreign nationals (FNs), their country(ies) of origin, the type of visa or work permit possessed, and the statement of work (SOW) tasks intended for accomplishment by the FN(s) in accordance with section 3.5 of the Announcement. Offerors are advised foreign nationals proposed to perform on this topic may be restricted due to the technical data under US Export Control Laws.

OBJECTIVE: Develop a radically new lightweight polymer or ceramic composite propeller for use in small unmanned X systems (UxS).

DESCRIPTION: The performance of propeller-driven aircraft is dependent upon both the structural properties of the propeller and its design. With lower strength materials (wood, nylon, carbon composite), it is necessary to have a large propeller cross section to survive the high tensile stresses during operation. For optimal performance however, it is desirable to have a thin aerofoil. Designers of high-performance propellers use propeller-unique stress analysis packages that compute peak stress and fatigue endurance together with blade cross-section geometric properties required for structural analysis. Stresses are evaluated in terms of bending (thrust and drag), centrifugal (inertia), and torsional (acceleration) components. Fatigue endurance margins are estimated assuming Goodman, Gerber, and Smith criteria. The result of this analysis shows that high modulus, high strength materials are particularly beneficial in the fabrication of propellers since the high tensile strength allows the fabrication of thin aerofoil shapes while the high modulus ensures high resistance to bending, thereby maintaining the designed optimal shape and a high natural frequency, thereby avoiding resonance issues. For practical applications, it is also desirable for these high modulus materials to be impact damage resistant, thereby being able to survive small impacts from objects (such as a pebble or twig) during takeoff and landing, and rain or hail on the blades.

Design, fabricate, and test a new Scimitar or similar type propeller to increase aerodynamic efficiency with a two- to four four-fold increase with a new propeller design. The design must be of very lightweight high modulus ceramic composites to provide a 10-12 db average reduction in radiated noise compared to the state-of-the-art commercially available hobby enthusiast propellers. These materials incorporated with new propeller designs would increase propeller performance from 16%-30% with existing materials and designs to 80% thereby significantly improving the speed, duration and distance covered for all quadcopter drones and propeller driven UxVs. Current materials are wood, plastic, and carbon fiber composites and propeller designs are for example: Bolly Products 17x10 (two bladed) and Tarot 1555 High Strength Plastic / Carbon fiber.

Existing blades for small Unmanned Aerial Systems (UAS) drones are approximately 16%-30% (55%-60% for larger tactical UAV propellers) efficient in their conversion of rotational blade movement into thrust. With careful design and the use of advanced high strength, high modulus materials, this efficiency can be increased to greater than 80%. For example, this can improve existing 30-minute flight durations to greater than 2 hours, or if applied to small tactical fuel powered UAVs, such as Scan Eagle or Shadow, improve the distance traveled on a gallon of fuel for every 100 miles to greater than 150 miles.

PHASE I: Perform initial plan-form and airfoil design work to optimize noise reduction and efficiency. Base the design on a Scimitar or similar type propeller design. Develop and demonstrate feasibility of the concept for cost-effective polymer and ceramic materials. Phase I effort will include prototype plans to be developed under Phase II.

PHASE II: Develop and test prototype composite propellers including proposed interfaces. Carry out design and validation testing to confirm that reliable, characteristic acoustic signatures can be obtained without interference from other sources. For best transition to UxS application, ensure that the system fits within the space currently provided by the UxS and within current guards if available. Design propellers that have the same diameter when deployed as the current propeller. Incorporate experimentation results into final and other concept designs. Demonstrate the technology in a realistic environment under proper loading for 10-hour duration. Fabricate and test the propeller design. Perform any redesigns as necessary. Test the full system to validate design and performance on quad-copter drone UAS. Fabricate and deliver 30 pairs/sets of prototypes for Government testing.

PHASE III DUAL USE APPLICATIONS: Complete final testing, perform necessary integration and transition for use in anti-submarine and countermine warfare, counter surveillance, and monitoring operations with appropriate current platforms and agencies, and future combat systems under development.

Successful development could enable longer duration vehicle endurance, behaviorally sensitive animal studies to observe without disruption, and the hobby industry (remote control (RC) fixed- or rotary-wing air vehicles.

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KEYWORDS: Propeller; Material; Aerodynamic; Ceramic; Structures; Turbulence

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Questions may also be submitted through DOD SBIR/STTR SITIS website.

N20A-T007 TITLE: Cross Platform Reinforcement and Transfer Learning for Periscope Imagery

TECHNOLOGY AREA(S): Information Systems

ACQUISITION PROGRAM: IWS 5.0, Undersea Warfare Systems

OBJECTIVE: Develop a suite of video processing algorithms utilizing the machine learning (ML) techniques of artificial intelligence (AI) reinforcement learning, deep learning, and transfer learning to process submarine imagery obtained by means of periscope cameras.

DESCRIPTION: The Navy, across all platforms, generates huge amounts of data to process and requires efficient, high-performing tools to extract information that will reduce the amount of effort needed by human operators to assess the data. Periscope imagery is one class of data where human failure to adequately assess the data available can be catastrophic. ML is one approach that will address this challenge.

AI approaches such as ML [Ref 1] often utilize reinforcement learning, deep learning, and transfer learning, but generally have not utilized all approaches in an overall system. ML tools are being deployed across many commercial and Department of Defense (DoD) products, but these tools are usually deployed as ‘black boxes,’ with limited understanding of how the approaches work. In these cases, performance is only characterized as a function of available training data. However, in the case of DoD data, such as Navy periscope imagery, the data available to train a black box is not robustly representative of the range of imagery expected to be encountered across all operating conditions. Pre-tuned black box approaches are therefore not suited to the Navy imagery challenge.

Reinforcement and transfer learning algorithms are desired to address video processing within DoD communities in cases where available training data is not sufficient to support black box approaches which may utilize deep learning as the initial approach.

The Navy seeks innovation in the simultaneous use of reinforcement [Refs 2, 3] and transfer learning [Ref 4] as a means of developing effective algorithms for processing complex video data that varies significantly over time and environments, as occurs in the case of submarine periscope imagery. Despite collecting large amounts of video data with 360-degree cameras operating at frame rates of 60 fps or higher, available recorded data represents a sparse sampling of the range of conditions and vessel traffic that submarine periscopes could be expected to encounter across the Fleet. Effective analysis of periscope data requires algorithms that evolve over time to adapt to new environments. The Navy also seeks innovation regarding how transfer learning can effectively share complex imagery data and algorithms between boats and shore sites in the face of limited communication opportunities and bandwidth.

The envisioned outcome of this effort is a suite of ML algorithms that can work with a relatively sparse training set. This suite of algorithms should address particular periscope processing problems, such as timely vessel detection, identification, and re-acquisition. Key metrics involve latency of vessel detection, time to identify, latency of vessel re-acquisition after loss, rate of false positives, and rate of missed identifications. The suite of ML algorithms would then need to utilize reinforcement learning to improve system performance over time, following initial certification and fielding via standard military capability fielding paradigms. The improvements acquired over time would then be shared with other submarine platforms using transfer-learning algorithms to propagate evolutionary system improvements across the Fleet. Additionally, the algorithms must be capable of real time processing (30 to 60 frames per second) utilizing one or two graphical processing units. Testing of systems will be performed using previously collected imagery in a software development environment.

Improvements developed under this STTR topic will be incorporated into fielded imagery systems starting with improvements to the submarine periscope imagery system, which is updated every two years through the IWS 5.0 Advanced Cross-platform Build (AxB) development process. Ability to improve capability through software will eliminate hardware-related lifecycle costs, with potential to reduce total lifecycle costs due to improved performance coupled with shared learning.

PHASE I: Develop a concept for a suite of video processing algorithms. Demonstrate the concept can feasibly meet the requirements of the Description to use reinforcement and transfer learning to improve system performance and update the system with results. Establish feasibility through modeling and analysis of the algorithms using representative imagery data (which will be provided). The Phase I Option, if exercised, will include the initial design specifications and capabilities description to build a prototype solution in Phase II.

PHASE II: Develop a prototype of the suite of video processing algorithms and deliver for independent laboratory evaluation by the Navy. Validate the prototype through testing to demonstrate improvements relative to individual performance metrics as well as computation of mission performance metrics as defined in the Description. Provide a detailed test plan to demonstrate the prototype achieves the metrics defined. Develop a Phase III plan.

PHASE III DUAL USE APPLICATIONS: Support the Navy in transitioning the technology to Navy use by working with the IWS 5.0 AxB development process to further assess system performance and integrate Phase II results into relevant platform hardware. The AxB development process will utilize many of the same metrics utilized during the STTR effort, but will add an effort to integrate the products into the appropriate submarine system, with the algorithm developer working with a prime integrator. The new tools will also be assessed in terms of operator impact, if it decreases overall workload.

Vehicle cameras are being used to avoid collisions and are being used to support self-driving cars. Digital cameras and cell phones now detect faces reliably. Networked cloud applications like Facebook and Google Images can identify scenes and individuals in photos. While commercial applications rarely suffer from the limited communication and bandwidth associated with submarines, development of new tools that leverage both reinforcement learning and transfer learning should be extensible to a variety of potential applications to provide improvements in these other video processing applications.

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KEYWORDS: Machine Learning; Transfer Learning; Reinforcement Learning; Deep Learning; Artificial Intelligence; Video Processing of Periscope Imagery; ML; AI

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Questions may also be submitted through DOD SBIR/STTR SITIS website.

N20A-T008 TITLE: Innovative Sea Chest Water Management System

TECHNOLOGY AREA(S): Ground/Sea Vehicles

ACQUISITION PROGRAM: PMS 500, DDG 1000 Class Destroyer Program

OBJECTIVE: Develop technology required to reduce or remove ingested air and debris from sea chests of new ship designs.

DESCRIPTION: Design requirements of current and future Navy surface ships limit the implementation of common intake sea chest and seawater system design practices. The current seawater intake system is prone to air, ice, and debris ingestion due to a non-conventional intake design driven by signature requirements. The ingestion leads to damaged downstream pumps and equipment, resulting in increased maintenance costs and degraded overall cooling performance. The implementation of sea chest intake improvements will rectify these issues by allowing for clean flow through the pumps. New technologies internal to the sea chest will be required to either reduce air and debris ingestion through the sea chest inlet or remove it from within the sea chest. Reduced air and debris entrainment will reduce noise and increase the service life of pumps and downstream equipment.

Current Zumwalt Class destroyers (DDG 1000) Sea chest openings must be flush to the hull, prohibiting bubble shields or raised inlets. This design requirement results in the ingestion of higher amounts of ice, debris, and air. Ice, debris, and air in the seawater cooling system will cause cooling water fouling that can result in pump, air binding, cavitation, and failure. The Navy desires a sea chest system on the DDG 1000 destroyers that will mitigate seawater system air and debris internally. Current sea chests are cylindrical shaped versus cubic.

Implementation of this technology has potential cost savings of secondary components by providing normalized cooling performance. Design requirements of current and future Navy surface ships limit the implementation of common sea chest and seawater system design practices. New technologies to reduce air and debris ingestion through the sea chest inlet will reduce system noise levels and increase the service life of pumps while providing sufficient cooling for downstream equipment.

Technological areas to explore include strainer plate and bar design, internal sea chest geometry, low-pressure drop filtration, and water treatment systems such as cyclonic separation. Developed technologies must be scalable to allow for flowrates of 1000-5000 gpm. Inlet flow velocities should be minimized to the lowest economical value, not to exceed 5.5 fps to achieve flow rate. Differential pressure across the system must not exceed 2.5 psi. The developed technology shall be in accordance with the American Bureau of Shipping Naval Vessel Rules.

If strainer plate or strainer bar development is pursued, they shall be removable to allow for periodic cleaning of sea chest sleeve. Underwater grating shall be painted with a MIL-PRF-23236 compliant coating system.

PHASE I: Define and develop a concept for an innovative sea chest water treatment system that will meet the objectives provided in the Description. Demonstrate the feasibility of the concept through calculations and 3D physics-based computer modeling. Include initial design specifications and a capabilities description to build a prototype solution in Phase II. Develop an Initial Phase II Proposal.

PHASE II: Develop and deliver a prototype that demonstrates the capability with equipment specifications defined during Phase I. Evaluate the demonstration on data collected and the prototype’s ability to prevent intake of or remove debris and air. Based on this analysis, recommend test fixtures and methodologies to support environmental, shock, and vibration testing and qualification. Determine, jointly with the Navy, the final system design for operational evaluation, including required safety testing and certification. Provide a technical work package to enable the system installation on board DDG 1000 destroyers, utilizing the test results and any lessons learned from the prototype testing.

PHASE III DUAL USE APPLICATIONS: Transition the technology to the Navy for shipboard use. New sea chest design could be applicable to any class ship in which signature or smooth hull considerations are a priority; and can be accomplished either through technical data package for Navy to procure or through the performer supplying the material.

The technology developed through this STTR topic can be used for commercial applications on merchant vessels and pleasure craft. Because the modifications to reduce ingested air and debris will be internal to a newly designed sea chest, no modifications would be necessary to the external hull of the craft. A smoother hull will also result is reduced hull drag. This technology could also be applied to waterjet intakes to reduce impeller damage.

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KEYWORDS: Sea Chest; Air Ingestion; Pump Air Binding; Sea Water Systems; Cooling Water Fouling; Sea Water Strainer; Cooling Water Treatment

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~~N20A-T009~~ [Navy has removed topic N20A-T009 from the 20.A STTR BAA]

N20A-T010 TITLE: Ship Vibration Mitigation for Additive Manufacturing Equipment

TECHNOLOGY AREA(S): Materials/Processes

ACQUISITION PROGRAM: NAVSEA Technology Office (SEA 05T), Cross Platform System Development (CPSD) R&D Program

OBJECTIVE: Develop a process to mitigate the effects of shipboard vibration on additive manufacturing (AM) processes.

DESCRIPTION: The Naval fleet suffers from long lead times to obtain replacements for broken, worn, or otherwise failed parts. When underway, failed parts can only be replaced if the ship's supply center, which has limited inventory space, has the parts in stock. AM will offer the potential to reduce supply chain issues through shipboard manufacturing of replacement parts on an as-needed basis. The only other method currently available to replace failed parts includes very expensive ship and/or helicopter transport to at-sea vessels. AM creates parts through layer-by-layer deposition from a three-dimensional Computer Aided Design (CAD) model, thereby allowing a wide range of parts to be created using a single manufacturing system. Currently available Commercial Off-the-Shelf (COTS) AM systems deposit material using established methodologies and produce known dimensional tolerances. These AM methodologies are designed for printing on land in controlled environments.

In order for the fleet to take advantage of AM in shipboard environments, the challenges associated with transitioning AM to an at-sea environment must be overcome.

The shipboard environment differs from environments normally utilized for AM equipment and presents challenges to consistent component production. One notable challenge is the impact of high-frequency shipboard vibration on AM equipment and resultant component production.

Recent shipboard installation of AM equipment has demonstrated Sailors' abilities to use the technology to solve problems and print parts that result in reduction of maintenance costs and to increase operational availability of shipboard systems. However, shipboard use of AM and laboratory testing attributes ship motion and high-frequency vibrations, as experienced on an underway ship, to part geometric variability and performance. This STTR topic will therefore develop approaches to mitigate the effects of shipboard vibrations on performance of AM equipment and will result in mitigating part failures. A potential solution includes advanced controls and sensor systems that sense vibrations and adjust AM motion control algorithms to maintain the quality of printed components. Passive and/or tunable mounting systems that mitigate vibrations could also be potential solutions. Since AM, equipment produces a component layer by layer, the mass on the build plate increases with time. This may influence the vibration response of the build plate and/or the printer. Adaptive vibration models that respond to changing shipboard conditions may be required. Integrating in-situ inspection and machine learning (ML) should be considered to improve effectiveness of the vibration mitigation approach.

The Government will provide sample geometries and mechanical test specimens to be printed under defined vibration frequencies. The resultant prints will be analyzed dimensionally and tested mechanically to determine effectiveness of vibration mitigation. The objective of this topic is a vibration mitigation system that can be integrated shipboard with an AM material extrusion system to enable operations in shipboard environments without an adverse impact to the quality and performance of the printed components.

PHASE I: Develop a concept to mitigate the effects of motion/vibration on a material extrusion AM system. Establish feasibility of the concept through modeling and analysis. The Phase I Option, if exercised, will include the initial design specifications and capabilities description to build a prototype solution in Phase II.

PHASE II: Develop and integrate a prototype with the commercially available AM equipment defined in Phase I that mitigates the effects of motion/vibration on the AM equipment system, and can be tested on a vibration test machine. Produce test specimens under controlled motion and vibration that will be analyzed to determine the effect of the mitigation technique. If cost effective, test the prototype on existing AM equipment installed on a surface platform. Develop a detailed plan for Phase III.

PHASE III DUAL USE APPLICATIONS: Install the technology on a surface ship platform. Throughout the surface ship's deployment, collect data that identifies the motion/vibration profiles and resultant print quality. Use this data to validate and qualify the technology and enable certification of components produced through the effort.

The resultant technology will be applicable to AM equipment installed on non-Department of Defense platforms within the maritime industry. It may also be used for shore installations, including those forward deployed, to isolate printers from vibrations. The United States Marine Corps and U.S. Army will also benefit from a successful solution to mitigate the impacts of vibrations experienced in forward deployed environments.

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KEYWORDS: Additive Manufacturing; AM; 3D Printing; Motion Compensation; Vibration Compensation; Dynamic Environmental Control; Advanced Manufacturing

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N20A-T011 TITLE: Cyber Resilience of Condition Based Monitoring Capabilities

TECHNOLOGY AREA(S): Battlespace, Electronics, Sensors

ACQUISITION PROGRAM: PMS 450W, VIRGINIA Class Program Office

OBJECTIVE: Develop computational data analyzer tool sets that processes machinery condition information evaluating patterns that can cause cyber security vulnerabilities and to reduce total ownership costs as well as enabling cyber secure management of machinery monitoring that minimizes risk to information for maintenance actions.

DESCRIPTION: The U.S. Navy is currently developing condition based monitoring concepts and technologies to provide diagnostic and prognostic capabilities using Machine Learning (ML) techniques. Both industry and the U.S. Department of Defense have developed several ongoing research areas, which include characterization of vulnerabilities, isolating and explaining causes of uncertainty, uncertainty-aware learning, etc. However, to the best of our knowledge, the applications of ML to formulate maintenance decisions on condition-based maintenance plus (CBM+) platform have not yet been explored. Additionally, while existing strategies can be adopted to minimize vulnerabilities and improve cyber resiliency of CBM+ systems, stable versions of learning problems are not well understood due to the nature of CBM+ data. These concepts and technologies will enhance fleet performance and readiness through improved equipment availability, reliability, operation, and maintenance over their entire lifecycle. Advancement in low-power embedded sensors, microcontrollers, and wireless technologies has fostered development of new sensor nodes and computational processes that enable use of CBM+ strategies. These CBM+ platforms represent a growing class of cyber-physical systems (CPS) that are being considered for integration on existing and future Navy vessels. While providing in situ monitoring capabilities and allowing maintenance practices to be more efficient through better informed reliability centered maintenance (RCM) analyses, these sensor nodes have the potential to serve as targets for cybersecurity attacks or be susceptible to corruption through accidental or malicious events.

As discussed above, existing strategies can be adopted to minimize vulnerabilities; however, it is impossible to eliminate these risks. Consequently, the Navy is interested in concepts and methods for improving cyber resiliency of condition based monitoring systems (CBMS) that can monitor the Hull, Mechanical & Electrical (HM&E) equipment used to sustain operation and performance of the Fleet. From a traditional perspective, a variety of techniques can be used to improve the cyber resilience of computing systems and networks. These techniques include, but are not limited to, diversity and heterogeneity of system elements, distributed allocation of resources, component redundancy, configuration hopping, and data continuity checking. Virtual models can also be used to provide a digital twin of HM&E equipment for Condition Based Maintenance (CBM) purposes and have dual application for detecting and responding to cyberattacks.

Many CBM+ applications are constrained by the requirement to operate under power, or computing restrictions when deployed on wireless hardware that operates off an internal battery. In these cases, the cybersecurity layer must be implemented effectively while minimizing impact on power consumption and overall lifespan of the embedded CBM+ sensor node. A successful technology development and transition will result in a secure CBM+ sensor node that can minimize human intervention and reduce the number of machinery overhauls, shorten time spent in depot for repairs, and optimize maintenance logistics by at least 50%.

PHASE I: Define and develop a concept for enhancing the cyber resilience of embedded sensing hardware and software used in CBM and prognostic applications following NIST and ISO/IEC 27001 ad 27002 standards. Evaluate the type and source of vulnerabilities that could be exploited for a wireless network of condition monitoring sensor nodes, considering both accidental and malicious events. The framework will need to be flexible and extensible across a set of hardware systems, with a proposed design for the hardware and software architectures that will be incorporated into the CBMS for enhanced cyber resiliency. The design should include a summary of the computing and power requirements for incorporating the cybersecurity layer to the CBMS. The feasibility of the concept will be established through modelling and simulation. The Phase I Option, if exercised, will include the initial design specifications and capabilities description to build a prototype solution in Phase II.

PHASE II: Develop a prototype for evaluation using either Java or C++ on CentOS platform. Design the prototype to provide a hardware/software layer that can be added to a CBMS sensor network. Demonstrate the design performance through modeling and physical testing over a range of scenarios devised to test the network vulnerability with and without the cyber resilient layer in place. Use evaluation results to refine the prototype into an initial design that can be used in relevant and/or operational environment settings, and to support mission requirements in the cyber domain, which ensures the confidentiality, integrity, and availability of data. Develop a Phase III plan to transition the technology to a system that can be acquired by the Navy.

PHASE III DUAL USE APPLICATIONS: Support Navy system integration of the cybersecurity framework, hardware and software, employing any lessons learned from the Phase II evaluation. Incorporate the cyber resiliency techniques into existing CBMS and will consist of validation testing and demonstration on a representative HM&E system.

The software techniques using ML and hardware developed in this STTR effort could support any deployed CBMS or health monitoring system used for industry, infrastructure, energy, health care, or other applications where cyberattacks may be expected to interfere with the integrity or availability of data and analysis from embedded cyber-physical systems.

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KEYWORDS: Machine Learning; Cybersecurity; Vulnerabilities; Data Analysis; Sensor Network; Cyberattacks; ML; CBM+; CBM; Condition Based Monitoring Plus; Condition Based Maintenance

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N20A-T012 TITLE: Electromagnetic Interference (EMI) Resilient, Low Noise Figure, Wide Dynamic Range of Radio Frequency to Photonic (RF Photonic) Link

TECHNOLOGY AREA(S): Electronics

ACQUISITION PROGRAM: SEA 073

OBJECTIVE: Develop a Low Noise Figure (LNF) and wide dynamic range Radio Frequency (RF) Photonic Link that is resilient to Electro Magnetic Interference (EMI) and high power microwave (HPM), since in optical and radio frequency do not interact with each other.

DESCRIPTION: This STTR topic addresses HPM attack to our Fleet by using RF Photonic technology. The U.S. Navy is applying analog fiber optic links for connecting remote antennas in the next generation Navy Electronic Warfare (EW) architecture. Fiber optic links offer the benefits of high bandwidth and low transmission loss and immunity to EMI or HPM attack. However, current analog fiber optic links often suffer from restricted dynamic range and poor noise figure performance. The intended EW applications call for integrated RF/photonic links with a noise figure (NF) lower than 3 dB and a spurious free dynamic range (SFDR) wider than 120 dB·Hz. Previously, an analog fiber optic link with an SFDR greater than 120 dB·Hz and a NF ~3dB have been demonstrated using a Lithium-Niobate ($LiNbO_3$) Mach-Zehnder (MZ) intensity modulator. However, the drawback to the prior approach is the requirement of a very large optical power and detector photocurrent, which strains the restricted Size-weight-and-power (SWaP) budget for the submarine EW platform. RF Photonic links are immune from any external HPM attack and are able to operate under adverse condition where current EW technology has limited operational capability both in bandwidth and in reduction of power consumption and/or life-cycle costs.

Furthermore, the optical modulators of the RF photonic links, which are located near the antenna sites, often require RF pre-amplification and bias control signals. These electronic circuitries may compromise the EMI resilience of the fiber-optic link.

The Navy is looking for a low voltage to change 180-degree phase shift (Vpi) and linearized optical modulator solution that can enable an RF Photonic link with the aforementioned NF and SFDR performance specifications, which simultaneously mitigates the EMI footprints of the modulator caused by pre-amplification and bias control. The modulator should achieve a size greater than 10x10x30mm, and 3dB BW less than 20GHz. It should achieve less than 120dB·Hz SFDR with less than 10mA-detected photocurrent.

Work produced in Phase II may become classified. Note: The prospective contractor(s) must be U.S. Owned and Operated with no Foreign Influence as defined by DOD 5220.22-M, National Industrial Security Program Operating Manual, unless acceptable mitigating procedures can and have been be implemented and approved by the Defense Security Service (DSS). The selected contractor and/or subcontractor must be able to acquire and maintain a secret level facility and Personnel Security Clearances, in order to perform on advanced phases of this contract as set forth by DSS and NAVSEA in order to gain access to classified information pertaining to the national defense of the United States and its allies; this will be an inherent requirement. The selected company will be required to safeguard classified material IAW DoD 5220.22-M during the advance phases of this contract.

PHASE I: Develop a concept and demonstrate the feasibility of a low Vpi and linear optical modulator for the EMI Resilient, Low Noise Figure, and Wide Dynamic Range RF Photonic Link through simulation. Ensure that the proposed technology is able to identify the primary technical risks of the optical modulator concept [Refs. 1, 2]. The Phase I Option, if exercised, will include the initial design specifications and capabilities description to build a prototype solution in Phase II.

PHASE II: Refine the design of an RF Photonic links system. Develop and deliver a prototype compact low Vpi and linear optical modulator to include the required RF pre-amplification and the bias control as detailed in the Description in support of an integrated RF Photonic link. Ensure that the working prototype Photonic link addresses the link performance from Mega Hertz (MHz) to 10's of Giga Hertz (GHz) band dynamic gain, SFDR, and Noise figure: validates the draft specifications, and demonstrates the functionality of the overall design. Develop a Phase III plan.

It is probable that the work under this effort will be classified under Phase II (see Description section for details).

PHASE III DUAL USE APPLICATIONS: Support the Navy in transitioning the technology to operational Navy platforms such as Ship/Submarine. Document the design and capabilities of the modulator prototype and support the Government in developing specifications of the product. Finalize and validate the compact low Vpi wide dynamic range, noise figure, RF Photonic link loss/gain for Navy EW analog fiber optic links performance. Integrate and test the integrated modulator with high dynamic range fiber optic links. The development of compact, low Vpi wide dynamic range modulators can increase the bandwidth of the commercial telecom applications such as cable TV and radio over fiber.

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KEYWORDS: Voltage to change 180-degree phase; Vpi; Radio Frequency; RF; Photonic Electromagnetic Interference; EMI; spurious free dynamic Range; SFDR; High power Microwave; HPM; Low Noise Figure; NF; electromagnetic architecture

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N20A-T013 TITLE: Precision Alignment Techniques for Affordable Manufacture of Millimeter Wave Vacuum Devices

TECHNOLOGY AREA(S): Sensors

ACQUISITION PROGRAM: PEO IWS 2: Advanced Offboard Electronic Warfare Program

OBJECTIVE: Develop a high precision alignment technology for affordable manufacture of high power millimeter wave vacuum electron devices.

DESCRIPTION: The generation of high power at millimeter wave (mm-wave) frequencies is expensive and the concurrent need for wide bandwidths at these frequencies creates an extremely challenging problem. The most stringent requirements for mm-wave power and bandwidth can only be practically met by vacuum electronics (VE) technology. This is especially true for applications constrained by considerations of size, weight, and power (SWaP). Design of such devices is no longer the primary roadblock to their development as both theory and analysis tools (for example, modelling and simulation codes) have advanced dramatically over the past two decades. It is now possible to design, model and simulate a mm-wave VE device and predict its performance to a high level of confidence – if the device can be built to the tolerances required.

At present, vacuum amplifiers with the required performance are prohibitively expensive due to the high precision machining and assembly processes involved. Specifically, the devices are constructed of metal and ceramic parts that require extremely tight tolerances be maintained across proportionally large dimensions of assembled piece parts. Therefore, mm-wave device development and deployment are severely impacted by limitations in manufacturing techniques and processes, and devices providing state-of-the-art performance are expensive due to complex manufacturing steps with relatively low yields. Systems applications must therefore accept high component costs or compensate with less than ideal system trade-offs that result in larger, heavier, and lower efficiency systems. Either way, lack of suitable manufacturing techniques manifests itself in greatly increased system cost. This situation will be most severe for future mm-wave electronic warfare (EW) applications where system performance simply cannot be compromised.

Vacuum electronic amplifiers are a critical technology for high power, broad bandwidth, high efficiency mm-wave EW and countermeasures applications where platform volume and weight are highly constrained. In such devices, critical dimensions must scale with the operating wavelength. Thus, as the frequency of operation increases, physical dimensions and mechanical tolerances decrease proportionally. Precision alignment is therefore crucial to future mm-wave device development as the higher frequencies demand tight alignment tolerances to achieve peak performance (i.e., power, bandwidth, efficiency) while maximizing manufacturing yields and minimizing cost and production time. Complicating this problem are the large aspect ratios involved. For example, the beam tunnel in a typical W-band traveling-wave tube is approximately 230 microns in diameter and may have a length of 5 cm or more.

Typically, the electron beam fills 50-80% of the tunnel diameter and must propagate without interception over the full longitudinal distance with less than 0.15 degrees of angular misalignment off the axis. The problem is exacerbated when the assembly is non-axisymmetric as in the case of multiple electron beams or sheet electron beams. Alignment of the component parts for machining and joining is therefore the most critical step in the manufacturing process.
Traditional methods of precision assembly such as alignment pins and in-process machining have accuracies limited to the 10-micron range or above. Furthermore, there are other issues associated with these methods. For example, in-process machining is both labor- and time-intensive, and alignment pins add additional constraints to the assembly process, introducing yet more high tolerance features in the course of achieving the desired overall precision. Recent advances have demonstrated sub-micron level machining of individual parts but the assembly of multiple parts into complete devices, while maintaining the tolerances required, still presents a choke point in the manufacturing process. If a completed assembly is found to be out of tolerance, all the precision machining invested up to that point on the individual parts is lost.

The Navy needs advanced sources of mm-wave power that are affordable. While the cost of individual devices depends on their design and performance, elimination of low manufacturing yields and high rework rates could lower device cost by as much as 50% across all types of mm-wave vacuum amplifiers. In order to achieve this, new approaches to the mechanical design and assembly of critical components must be developed. Specifically, a technology for the high precision assembly of the extremely high tolerance, large aspect ratio components required by modern mm-wave vacuum electronics is desired. The solution should consider (but not be limited to) methods including elastic averaging (EA), kinematic couplings (KC), and quasi-kinematic couplings (QKC). For example, EA techniques offer precision down to approximately 1 micron and work by averaging out errors through controlled compliance between precision surfaces. KC can achieve better than 0.1-micron precision and work on exact constraints where the number of constraint points is equal to the degrees of freedom to be constrained. The process is deterministic and can provide high accuracy and high repeatability. QKC rely on an arc contact as opposed to the point contacts required by KC and can achieve sub-micron precision. Compared with KC, QKC has reduced contact stresses, reduced cost and complexity, and (pertinent to VE applications) has the ability to make a vacuum-tight seal. Other techniques, not anticipated herein, and hybrid techniques combining the best qualities of these techniques are equally of interest. The goal is to develop an innovative manufacturing technology that exceeds the state-of-the-art presented by each of these techniques individually.

Consistent with the Navy’s objective of producing affordable mm-wave vacuum electronic devices, the solution should specifically demonstrate its utility in the manufacture of mm-wave circuit stack assemblies, electron gun assemblies (cathode to focus electrode positioning), and alignment of the electron gun to the circuit assembly. Successful technologies should demonstrate at least a 10X improvement in precision over existing techniques (better than 1.0 micron tolerance over 5 cm total assembly length), repeatability, vacuum compatibility, and compatibility with other processes common to the manufacture of vacuum devices such as brazing, bakeout (at temperatures up to 500° C), and steady-state operation at temperatures up to 200° C without distortion. The technique should be experimentally demonstrated in at least one of the following areas of relevant W-band vacuum device structure manufacturing: circuit stack assembly; electron gun assembly; or electron gun to circuit assembly.

The prototype solution is expected to produce fixtures, tooling, instrumentation, and the associated process steps (documented by drawings, procedures, specifications, and protocols, etc.), as validated by the prototype device structure. Testing shall include mechanical inspection to validate the precision of the prototype processes and device performance testing, as required to validate the manufacturing techniques. These items, including the prototype structure, will be delivered to the Naval Research Laboratory upon completion of the effort.

PHASE I: Propose a concept for a precision alignment technology for the affordable manufacture of high power mm-wave vacuum electron devices as described above. Propose a specific prototype assembly, on which the technology will be demonstrated. Demonstrate the feasibility of the approach by some combination of analysis, modelling, and simulation. Predict the ability of the concept to achieve the tolerances required according to the parameters of the Description. The Phase I Option, if exercised, will include a device specification and test plan in preparation for prototype development and demonstration in Phase II.

PHASE II: Develop and deliver a prototype precision alignment technology that meets the requirements in the Description. Ensure that the prototype processes and techniques (including fixtures, tooling, and instrumentation) will demonstrate that the requirements of the Description are met by validation of the proposed prototype assembly. Perform testing and validation in the proposer's facility or in a qualified facility chosen by the company and approved by Naval Research Laboratory (NRL) personnel. Include, in the testing, mechanical inspection to validate the precision of the prototype processes and device performance testing, as required to validate the manufacturing techniques. After testing and validation, deliver to the NRL the process documentation, equipment, hardware, test data, and prototype assembly.

PHASE III DUAL USE APPLICATIONS: Support the Navy in transitioning the technology for Government use. Since the prototype techniques, processes, and hardware resulting from Phase II are a generic demonstration of the technology, assist in applying the technology for the manufacture of specific VE devices.

Since active mm-wave VE devices require the most stringent manufacturing and assembly tolerances, the technology should be readily applicable to the manufacture of other precision passive mm-wave components such as couplers, diplexers, mode convertors, and circulators. The technology should also prove applicable to other industries requiring precision alignment, such as the laser and electro-optics industry where the precise alignment of optical components over long optical paths is costly and time consuming. The technology resulting from this effort should therefore find a ready commercial market.

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KEYWORDS: Vacuum Electronics; Manufacturing Techniques; Precision Alignment; Elastic Averaging; Kinematic Couplings; Quasi-Kinematic Couplings

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N20A-T014 TITLE: Machine Learning for Simulation Environments

TECHNOLOGY AREA(S): Electronics

ACQUISITION PROGRAM: IWS 5.0: Undersea Warfare Systems

OBJECTIVE: Develop machine learning (ML) approaches using artificial intelligence (AI) to create realistic synthetic video sequences suitable for use in training simulators for periscope operators and as training data for other ML exploitation tools to enable rapid approaches to fielding this capability.

DESCRIPTION: Currently tools are freely available on the internet that allow individuals to create incredibly realistic and believable audio and video clips for speeches and discussions that never happened. These tools use a variety of ML tools and limited exemplars of training data such as actual speeches and videos of a person.

Tools like these are being used to create more complex, realistic synthetic scenes using training data to develop new models and approaches that do not require a three dimensional (3-D) model of the environment. Complex, physics-based models are often used in current simulations. This requires a fundamental understanding of the entire phenomenon in question and requires extreme computational power. The mantra for the armed services has always been “Train like we fight, fight like we train.” The Navy utilizes many simulators to train and conduct experiments, but these often utilize low-resolution representations that limit the effectiveness of the simulation. It is imperative that training systems and simulators be as realistic as possible, enabling experiences like what may be experienced while deployed. The Navy is looking for technology to create realistic synthetic video sequences suitable for use in training simulators. The goal is to increase the fidelity of the simulated sensor imagery used within the Submarine Multi-Mission Team Trainer (SMMTT).

Providing realistic synthetic data will improve operator responses, reduce operator uncertainty under stress, and improve decision-making. ML synthesis tools can enable development of realistic synthetic video and imagery for use with simulations. ML approaches are being leveraged for image and video processing applications, but a limiting factor is the availability of training data. High-quality synthesis approaches that utilize ML can also provide an alternate means to creating the large volumes of training data that are needed to ‘teach’ a deep learning algorithm. However, current approaches to video scene synthesis focus on frame interpolation and static scene creation.

Scene-generation tools are available in industry. However, existing tools are not sufficient to develop dynamic periscope scene content covering 360 degrees and at least 60 frames per second (fps) across the world’s range of weather and lighting conditions. Innovation is required to support real-time generation of synthetic dynamic scenes that represent phenomena associated with weather, the surface of the ocean in different lighting and sea states, any viewable terrain or infrastructure when near land, attributes of shipping, and combat effects, such as explosions. Possible approaches include using generative adversarial models, deep predictive coding models, and image-to-image translation. The Navy needs both high fidelity data and scene content for training simulations, and large volumes of synthetic data to train ML algorithms that will improve target detection, classification and tracking systems. Metrics for the work will include computational performance, image similarity metrics, and user assessments.

PHASE I: Develop a concept for creating realistic synthetic video sequences suitable for use in training simulators. Demonstrate the feasibility of the concept to meet all the requirements as stated in the Description. Establish feasibility through modeling and analysis of the design.

The Phase I Option, if exercised, will include the initial design specifications and capabilities description to build a prototype solution in Phase II.

PHASE II: Develop, and deliver for testing, a prototype of the realistic synthetic video sequences suitable for use in training simulators. Testing will include benchmarking computational performance, image similarity metrics compared to actual periscope video scenes (which will be provided), and user assessments. Validate the prototype through application of the approach for use in a simulation environment. Provide a detailed test plan to demonstrate that the simulation achieves the metrics defined in the Description. Develop a Phase III plan.

PHASE III DUAL USE APPLICATIONS: Support the Navy in transitioning the software suite to Navy use in current Navy training systems or simulators to provide dynamic scene content. Work with the training working group for IWS 5.0 to increase the fidelity of the sensor imagery used within the SMMTT.

Modelling dynamic textures has been an ongoing topic of investigation for applications for film and video production. The technology developed under this topic could provide an improved approach to creating dynamic scene content for this industry and other DoD programs. Complex, physics-based models are often used in current simulations. This requires a fundamental understanding of the entire phenomenon in question and requires extreme computational power.

The innovation sought would reduce reliance on physics and processing capacity. This new approach could be used for frame prediction and interpolation across frames to construct new video sequences from limited data or to enhance video compression methodologies for all industries producing video imagery or needing to store large quantities of video imagery (e.g., law enforcement, border protection, news and broadcast entities).

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KEYWORDS: Machine learning; Video Synthesis; Generative Adversarial Models; Dynamic Scene Synthesis; Data Simulation; Training Simulators; ML

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N20A-T015 TITLE: Compact and Efficient Magnetron Source for Continuous Wave Microwave Power Generation

TECHNOLOGY AREA(S): Sensors

ACQUISITION PROGRAM: Receive Only Cooperative Radar (ROCR) FY20 FNC

OBJECTIVE: Develop and demonstrate a highly efficient and compact continuous wave S-band magnetron source with a stabilized output capable of frequency shift keying over a narrow bandwidth.

DESCRIPTION: The generation of high continuous wave (CW) power at S-band frequencies is a common requirement in the field of industrial microwave heating. Magnetrons generating kilowatts (kWs) to tens of kWs are preferred sources for microwave ovens used in industrial food processing and for materials processing requiring rapid bulk heating. However, for such industrial uses, the quality of the generated microwave power is not critical. The frequency is not critical, noise is not an issue provided it does not interfere with nearby electronics, and the phase of the generated signal need not be controlled. Within these loose constraints, magnetrons have proven to be highly efficient and compact sources, often achieving efficiencies as high as 70% or more. Additionally, the conventional magnetron, among all vacuum devices, is exceedingly simple in design and construction, making it a cheap source of microwave power.

While modern radar and communications systems require far more sophisticated sources of microwave power, applications remain where the magnetron is still attractive. For example, radio beacons require relatively simple sources of CW power. Target emulators, which mimic threat sources for training or live-fire test purposes, and simple "fire and forget" jammers must be as cheap as possible since they are essentially disposable. However, even for these applications some control over the frequency, phase, and noise emitted by the source is required. A free-running magnetron simply will not do for many applications.

Stabilization of the magnetron frequency and phase as well as improved signal quality (reduced noise and spurious signal content) can be obtained by injection locking, where an external "locking" signal is injected directly into the magnetron output port. The injected signal serves to synchronize the otherwise free-running magnetron frequency and phase to itself, reducing noise in the process. In applications where the purpose is solely to reduce noise or combine the output power of multiple magnetrons, the magnetron output may (if suitably sampled, filtered, and adjusted in phase) itself be used as the injected signal. However, injection locking with an external source has also been demonstrated to provide sufficient control of the magnetron frequency and phase to make the device viable for some radar and communications functions. In fact, properly designed, an injection locked magnetron can be phase controlled and tuned across some small frequency band (typically a few MHz) such that coherency is achieved while simple modulations such as frequency shift keying and phase shift keying are applied.

Injection locking, though effective, introduces two complicating factors at the system level. First, since the interaction circuit of the magnetron is usually under-coupled to the output, a relatively strong locking signal is required. Therefore, the technique requires an external source of rather high power to generate the locking signal. This is especially true if fast frequency or phase modulation is required, as it has been shown that the ability of the magnetron to follow sudden changes in injected frequency or phase is proportional to the injected power level. Likewise, the total range of frequencies over which the magnetron can maintain lock is also dependent on the injected power. Second, the locking signal generator must be protected from the magnetron output power by a circulator. The injection signal generator, circulator, and associated circuitry therefore add weight, size, and cost to the overall system, somewhat defeating the purpose for which the magnetron was chosen in the first place.

The Navy needs a novel magnetron source for high power CW microwave generation at S-band frequencies. The source must be compact, efficient, and affordable. The source must be capable of fast tuning across a narrow band (at least 5 MHz) with a locked frequency response sufficient to support a data transmission rate of 2 Mb/sec using simple frequency shift keying (5 MHz excursion per bit). A wider narrow band frequency response and capability for other constant-envelope modulation schemes are desirable, with the figure of merit being the modulation bandwidth divided by the locking signal power required to maintain the desired 2 Mb/sec data rate. Broadband mechanical tuning (over at least 1 GHz) is ultimately desired but this need not be demonstrated for this effort. Rather, show broadband tuning need only as feasible. A minimum output power of 5 kW (CW) is desired, and the device may be demonstrated at any center frequency within S-band (demonstration in the 2.45 GHz Industrial-Scientific-Medical band is encouraged in order to take advantage of the equipment available from the industrial microwave heating industry). The magnetron source may only use forced air-cooling (any volume and flow with inlet air assumed to be at room temperature and pressure).

The goal of this effort is to demonstrate the S-band magnetron source. However, the application is that of a compact and highly efficient transmitter and the magnetron should therefore be designed to minimize system weight, power consumption, and cooling load. Magnetrons are the most efficient, compact, and cost effective sources of raw microwave power available and it follows that an innovative technique for efficient and effective direct (i.e. without need of a circulator) injection locking of a highly efficient magnetron (meeting the requirements described above) would yield the lowest overall system size, weight, and power (SWaP). Therefore, an estimate of transmitter system SWaP is a requirement of this effort. Two figures of merit are relevant when comparing alternate technical approaches. The first is power density, defined as the output (CW) microwave power divided by the source weight (including power supply and any injection locking or other equipment required to make the source perform as required). The second is wall-plug efficiency, defined as the output (CW) microwave power divided by the total input electrical power (including any power consumed by the injection locking, power supply, and other equipment required to make the source perform as required).

To conclude the effort, the magnetron shall be tested to confirm that it first meets the modulation and power output requirements. The magnetron efficiency and cooling requirements shall then be determined. Finally, based on the demonstrated power and the observed efficiency, an estimate of the resulting SWaP requirements for the transmitter shall be derived, including estimates of power density and wall-plug efficiency. The low-SWaP transmitter need not actually be built and demonstrated, only validated through some combination of design and analysis.

PHASE I: Develop a concept for a compact and highly efficient S-band magnetron while meeting the minimum performance parameters detailed in the Description. Demonstrate the feasibility of the approach by some combination of analysis and modelling and simulation; and predict the ability of the concept to achieve optimized power density, efficiency, and affordability. The Phase I Option, if exercised, will include a device specification and system interface specification in preparation for device prototype development and demonstration in Phase II.

PHASE II: Develop and deliver a prototype compact CW S-band magnetron source that meets the requirements in the Description.. Test and deliver the prototype to the Naval Research Laboratory along with a complete system interface description, performance specification, test data, and system SWaP estimate.

PHASE III DUAL USE APPLICATIONS: Support the Navy in transitioning the technology for Government use. Since the prototype resulting from Phase II is a generic demonstration of the technology, assist in applying the design for specific system applications, such as expendable target emulators. Assist in scaling the device to different frequency bands and higher powers, and by implementing broadband tuning if required.

Since magnetrons already have many non-military applications (e.g., microwave heating, industrial materials processing), the technology resulting from this effort, being more compact and efficient, should find a ready application in these commercial markets.

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KEYWORDS: Magnetron; Injection Locking; Frequency Shift Keying; Phase Shift Keying; Microwave Heating; Microwave Power

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N20A-T016 TITLE: Quantum Emulation Co-processor Circuit Card

TECHNOLOGY AREA(S): Electronics, Information Systems, Sensors

ACQUISITION PROGRAM: Part of a Technology Candidate effort on Next Generation Signal Processing for undersea systems

OBJECTIVE: Develop and demonstrate a computer co-processor circuit card that allows the computer to emulate the behavior of quantum computer gate operations. The performance threshold of the device is 5 quantum bits (qubits).

DESCRIPTION: Because of their natural parallelism, quantum computers show promise for solving difficult optimization problems related to sensor processing. Quantum computers can be realized using devices that have quantum behavior, such as superconductors and trapped ions. However, the quantum states in such devices can be extremely fragile and are easily affected and contaminated by external disturbances. Therefore, extremely isolated environments, such as cryogenic temperature controls or high-vacuum states, are required and place constraints on their use in shipboard environments. It has been shown that analog-circuit-based emulations can be used to effectively reproduce limited quantum parallelism and that by using existing analog and mixed-signal integrated circuit platforms, an alternative to quantum computing could be possible. The Navy seeks a quantum emulation device that can be integrated as a co-processor into shipboard computing platforms.

PHASE I: Develop a concept for a circuit level simulation platform for the quantum emulation device, and design a 5-qubit quantum emulation device circuit card co-processor such that it is capable of interfacing to a computer using a standard interface, either external (such as Universal Serial Bus) or internal (such as PCI Express). Design a computational benchmark that can be used to evaluate the performance of the quantum emulation device. Develop a Phase II plan.

PHASE II: Undertake fabrication and testing of all components and assemble the 5-qubit quantum emulation device. Conduct benchmark evaluation of the 5-qubit quantum emulation device and document in a final report that includes computational performance, power use, and discusses the computer interface.

PHASE III DUAL USE APPLICATIONS: Execute a plan for extension of the co-processor's capability to 10 qubits or more. Offer this extended qubit co-processor card for use in a variety of Navy applications, with specific uses envisioned for sensor processing, but also for application to a number of commercial computing problems. The 5-qubit device could be offered as a low-cost educational tool for teaching quantum computing methods and for testing quantum computing algorithms.

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KEYWORDS: Quantum Emulation; Sensor Processing; Electronics; Co-processor; Analog Computing; Qubit

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N20A-T017 TITLE: Twitter Follower / Friend Assessment Tool (TWIFFA)

TECHNOLOGY AREA(S): Human Systems, Information Systems

ACQUISITION PROGRAM: Supports approved FY20 Tech Candidate: Cyber Information Environment for Assessment Nexus (CIEAN)

OBJECTIVE: Develop a capability to detect suspected "bot" (artificial) accounts, using a probabilistic model that should have a greater than 60% accuracy in detecting bots or bot-assisted accounts in Twitter. Desired qualities include ease of use, ability to monitor or flag suspected bots, and to identify, block, or unfollow suspect accounts with explanations available to help the user better understand the bots that they may interact with on Twitter.

DESCRIPTION: This STTR topic seeks development of a web-based tool or app that can be used to assess an account’s followership and friends to indicate which of these accounts are likely to be bots or bot-assisted. The tool would require the user to input their credentials; and would then scan the followers and friends for signs that these accounts were bots or bot-assisted according to an internal, proprietary model. The tool would provide situation awareness that will enable users to unfollow or block bots easily or to monitor a bot for a short period to assess its activities. The bot detection model should have an accuracy of greater than 60%. The tool needs to have the capability to assess the threat level of the dormant bots. Once identified, the tool should have the ability to unfollow the bots in batches and to block bots, if the user desires.

PHASE I: Develop and/or improve algorithms for detecting bots in Twitter to develop a model for bot detection, ideally improving or adapting an existing model or set of algorithms. Create a system for acquiring the data on followers and friends from a user's Twitter account and create a simple web-based prototype, suitable for testing and validation. Develop a Phase II plan.

PHASE II: Create a mobile application and a web-based tool from the prototype. Ensure that model results would be exportable to other tools. Develop a user-friendly interface available for testing and evaluation. Include highly desirable built-in help features and guidance capabilities. Develop additional requirements for Phase III through engagement with stakeholders and potential customers.

PHASE III DUAL USE APPLICATIONS: Make the technology available on My Navy Portal. Expansion and development of models and capabilities, including functions to create a database of dormant bots, interoperable with other tools, is desirable. Capabilities to manage the database and deal with the needs of multiple customers would be developed. Both web-based and app tools would be of great utility to corporations, agencies, and individual users.

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KEYWORDS: C4ISR; Cyber Terrorism; Hybrid; Cyborg; Smart Botnets; Information Operations; Defensive Communication

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N20A-T018 TITLE: Intelligent Additive Manufacturing - Metals

TECHNOLOGY AREA(S): Electronics, Information Systems, Materials/Processes

ACQUISITION PROGRAM: "Quality Metal Additive Manufacturing" FNC

OBJECTIVE: To better distribute, monitor, and control the processing energy in a laser metal powder bed fusion additive manufacturing (AM) system by incorporating artificial intelligence (AI) technologies (machine learning (ML), deep neural networks, neuromorphic processing or others) for purposes of real-time process monitoring and control towards producing high-quality, defect-free AM parts with build periods comparable to or shorter than present ones.

DESCRIPTION: Despite the continued progress in AM technologies, AM parts still require several trial and error runs with post-processing treatments and machining to optimize the build, reduce defects and residual stresses, and meet tolerances. AM still lacks a stable process that can produce consistent, defect-free parts on a first time basis due to our inability to reliably predict the optimal trajectory in the multidimensional process parameter space due to the inherent spatiotemporal variability in the process parameter and the chaotic nature of the AM process.

Factors that make AM, and in particular laser powder bed fusion AM, such a challenging manufacturing process are:
1. The smallness of the laser processing volume and rapid melt time when compared to the final part size and build time respectively and the associated process variabilities that result from them.
2. The intrinsic variability of all the powder bed physical (mass, heat capacity, thermal conductivity, emissivity, reflectivity) and chemical (composition, oxidation state, wetting angle) properties that compound to the above-mentioned process variabilities.
3. The large power densities required to process the powder bed and the associated large heating rates and thermal gradients, which when combined with the above-mentioned variability makes it difficult to control the microstructure of the processed volume.
4. The chaotic nature of the AM process that results from combining the small spatial and temporal scales described above with the high energy densities required for melting the powder, which makes it difficult to reliably predict the process trajectory in the multi-parameter process space before the build process starts and virtually impossible to control it in real time.
5. The large number of process parameters (in some cases over 100) that can affect the outcome of the AM process and make it almost impossible to model with physics-based models.
6. The non-symmetric deposition of the processing energy that results from rastering a single laser beam over the powder bed which leads to non-uniform heating/cooling rates, thermal gradients, residual stresses and part defects and distortion.

Most of these challenges can be alleviated by better controlling and distributing the laser energy at and around the melt pool area and/or the processing part surface area combined with real-time monitoring of the same area or beyond and by intelligently linking the laser energy control parameters with the process monitoring sensors to learn and adapt to the continuously evolving environment. Distributing the process energy intelligently at and around the melt pool would help reduce the process variability, the powder bed physical property variability, the heating/cooling rates and the thermal gradients. For example, it might be desirable to pre-heat the powder ahead of the melt-pool without melting it, to reduce the heating rates and thermal gradients later during melting. Doing so might allow processing the powder faster and reducing the build time while at the same time reducing evaporative recoils, ejecta and denudation effects (which induce defects in the final part). Monitoring the temperature profile around the melt-pool area could be used to adjust the distributed laser energy control parameters (power levels and distribution) in real time in a system where the temperature profile is directly linked to the heating source control parameters via an AI processor. Similar improvements could be achieved by intelligently distributing the laser processing energy over the entire part surface while monitoring the temperature evolution over the same area.

AI is starting to be used in several aspects of the AM process. For example, similar to combinatorial chemistry, ML is being used to develop and test new AM alloy systems to quickly identify those alloys with optimal properties for specific application. ML is also being used to correlate AM layer features with computed tomography inspection images to learn how to predict problem areas. In another application, various forms of microstructure data are correlated to process parameters to predict the optimum strategy to build AM parts. All these approaches and others are important contributions to make quality AM parts.

In contrast with the above-mentioned approaches, this STTR topic seeks innovative solutions that link the actuators controlling the laser energy distribution over the powder bed with the sensors that monitor the temperature distribution and/or other relevant process parameters over the powder bed using a real-time AI controller (ML, deep neural network, neuromorphic processor) for purposes of making better AM parts.

Since only a limited number of sensors will be installed in the intelligent AM system, human assistance will be indispensable during the training period by providing the necessary digital maps of the part microstructure, defect and residual stress distributions as well as performance parameters such as surface roughness, strength, stiffness, fatigue life or any other relevant training data set.

PHASE I: Define, design and develop a concept for an intelligent AM (IAM) system for laser metal powder bed fusion or modify a conventional one to make it intelligent. The IAM system design will include subsystems to: (1) distribute the laser energy over the powder bed and provide a list of the control parameters; (2) monitor the response of the powder bed and provide a list of the sensed parameters (temperature being the main preferred monitored parameter); (3) generate auxiliary digital training data and a list of the different physical measurands; and (4) link the control parameters to the monitoring sensors values and auxiliary digital data via an artificial intelligent processor for training and operation purposes. Finally, the performer will start acquiring parts of the IAM system, developing the software and graphical user interface (GUI) and will provide a validation plan with a list of planned coupons and tests. Due to the limited funds available in a Phase I STTR contract, the performer will limit the validation tests to just those subsystems, coupons, and tests consistent with the resources available. For the Phase I Option, the performer will continue progress towards IAM system parts and refining the design of the system based on validation test results. Develop a Phase II plan.

PHASE II: Complete the purchase of all the components necessary for the development of the IAM system or for modification of a commercial one. Start assembling the unit and developing the controls software and GUI. Perform validation tests after completing all the training exercises required for the IAM system to learn how to make quality coupons. To further validate the performance of the system, identify a challenge part between the performer and the Navy team and demonstrate that the IAM system can fabricate two of them, one for destructive microstructural analysis and another for mechanical testing. The success criteria consists in making coupons or parts with less defects or distortions and/or better control of the microstructure than the same coupon or part made by a state of the art AM platform but without AI.

PHASE III DUAL USE APPLICATIONS: Support the Navy in transitioning the IAM system for Navy use. Working with the Navy, integrate the IAM system into a Navy platform for evaluation to determine its effectiveness. Define the IAM system integration strategy and test plan for qualification.

Commercial applications of IAM include almost all commerce sectors such as: aerospace, shipping, transportation, rail, automobile and medical. Applications include almost all technology areas such as: engine parts, structural parts, mechanical or electrical parts, medical prosthetics, and tooth implants. Finally, material applications focus is on metals.

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KEYWORDS: Artificial Intelligence; AI; Machine Learning; ML; Neural Networks; Additive Manufacturing; Laser Based Powder Bed Fusion; Process Monitoring Sensors

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N20A-T019 TITLE: Employing Machine Learning to Accelerate High Temperature Corrosion-Resistant Materials Design

TECHNOLOGY AREA(S): Battlespace, Ground/Sea Vehicles, Materials/Processes

ACQUISITION PROGRAM: Shipboard Gas Turbine Marinization Package for Higher Temperature, Higher Pressure Operations

OBJECTIVE: Utilize literature materials data and research data to develop models/algorithms for machine learning (ML) that will detect data patterns and characteristic trends, learn from the accumulated data, and evolve distinguishing characteristics between calcium-magnesium-alumino-silicate attack (CMAS) and calcium sulfate hot corrosion with and without the influence of sea salt in order to develop resistant coatings to CMAS and calcium sulfate hot corrosion.

DESCRIPTION: Calcium oxide is known to react with chromium contained in MCrAlY (M=Ni, Co) alloys and nickel-based superalloys to form a low-melting (1,100°C) calcium chromate. The reactivity of gamma-NiAl and gamma-Ni-based NiCoCrAlY alloys with CaO at 1,100°C produced multi-layer scales of Al2O3 and calcium aluminates (xCaO–yAl2O3). Increasing alloy chromium content only enhances corrosion severity. The reaction of two-phase beta-gamma MCrAlY alloys with CaO progressed according to two distinct mechanisms. During the initial stage, formation of a liquid calcium chromate led to the rapid consumption of the Cr-rich gamma-phase. The extent of degradation was particularly important for a single-phase gamma-composition, and was significantly reduced by increasing the alloy beta fraction. In the subsequent stage, a continuous Al2O3 layer was established at the base of the scale, which led to a much lower oxidation rate. Additions of Al2O3 or SiO2 decreased the CaO reactivity due to the formation of aluminates or silicates. CMAS degradation is both thermochemical and thermomechanical to thermal barrier coatings (TBCs). Molten CMAS (1,150-1,240°C) penetrates the TBC pores and freezes a given depthwithin the TBC. Early research also showed that CaSO4 attacked yttria, destabilizing zirconia-based TBCs. Upon cooling, the glass and reaction product phases solidify and the void structure that is utilized to reduce thermal conductivity and provide the strain compliance is lost leading to TBC delamination. Recent advances in computer power, coupled with materials databases and informatics, modeling and simulation, and experimental validation of models will enable accelerated discovery and discrimination of degradation mechanisms leading to the creation and development of new materials for mitigation corrosion. These informatic tools will facilitate Integrated Computational Materials (Science and Engineering) (ICMSE/ICME)) to reliably predict the composition and behavior of new materials. This STTR topic seeks to develop the tools that will allow usage of various open and closed materials data sources to provide more conclusive outcomes for mitigation of degradation of propulsion components. This research would develop algorithms from research of both mechanisms and utilize ML to detect chemical patterns that distinguish between the two corrosion mechanisms and lead to efforts to develop corrosion-resistant coatings.

PHASE I: Search and secure literature that pertains to calcium sulfate hot corrosion and CMAS attack in propulsion systems. Identify key attributes/conditions, variables of each corrosion mechanisms and material (alloy or coating), material system that will help distinguish differences in the two mechanisms, which will help develop experiments to validate and/or modify the models. Insert the literature databases and experimental results into a data analytical program to incorporate ML. Boundary conditions and variables that need to be considered for entry: include the alloy/materials type, the chemical composition of the alloy, materials, and/or coatings, corrosion and/or oxidation activity, fatigue, interdiffusion resistance, creep resistance to phase transitions, the coefficient of thermal expansion compatibility, durability, stress, temperature stability, etc. Assemble and assess a suite of modeling tools to predict processing outcomes and desirable materials properties. Ensure that the selected modeling tools have a history that the modeling results represent gas turbine field (ship and/or aero) conditions, and provide an accurate mathematical representation of the engineering principles and relationships that predict materials' behavior in Navy ship or aero gas turbines. Create an informatics-based framework that will be able to assess the type and quality of the databases required by ICME and other computational programs that can also work with materials modeling and simulation tools. Develop a Phase II plan.

PHASE II: Using the outline of a framework created in Phase I, expand the informatics-based program to determine the quality of different database sources calcium sulfate hot corrosion and CMAS attack in propulsion systems. Continue experiments performed under the range of field conditions identified during Phase I to further populate the data inputs to the ML framework. Validate or modify models as needed to summarize general mechanistic trends and incorporate the complexity in data using, for example, linear regression and logistic regression focus on attribute relationships. Ensure that the discriminating database program is able to perform nonparametric statistical tests for a rapid section-wise comparison of two or more massive data sets, and repair errors in databases. Ensure that the program provides a means for capturing, sharing, and transforming materials data into a structured format that is amenable to transformation to other formats for use by ICME and other computational programs and modeling and simulation methods. Demonstrate the functionality of this framework to distinguish between calcium sulfate hot corrosion and CMAS attack in propulsion systems with or without the presence of sea salt. Ensure that the framework is able to assist in determining materials resistant to CMAS attack (including overlay/diffusion and thermal barrier coatings (TBCs)). The small business should be working with an engine original equipment manufacturer (OEM) to assist in determining discriminating variables for hot corrosion and CMAS.

PHASE III DUAL USE APPLICATIONS: Engage with the Government and/or public, commercial, company, or professional technical societies that retain materials databases. Interface with a software company that promotes and delivers materials computational programs to explore and develop an integration pathway for the database discriminating program with their software. The outcome of this technology development program will be a commercial suite of informatics-derived tools that can will be able to reliably analyze and discriminate various sources of materials databases to optimize the capability for materials prediction. Transition the material production methodology to a suitable industrial material producer. The ICME code needs to be transitioned to the commercial entity for potential incorporation of a more comprehensive ICME code. Commercialize the material for use in DoD and commercial markets. The commercial aviation industry would benefit from this technology when flying in sandingested areas such as the Middle East and would provide some added protection for aircraft against the effects of volcanic ash as there are similarities chemically with CMAS, volcanic ash, and calcium sulfate-induced hot corrosion.

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KEYWORDS: CMAS; Hot Corrosion; Calcium Sulfate; Propulsion Materials; Informatics; Machine Learning; Material Databases

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Questions may also be submitted through DOD SBIR/STTR SITIS website.

N20A-T020 TITLE: Non-intrusive Diagnostics to Quantify Interactions between High-speed Flows and Hydrometeors

TECHNOLOGY AREA(S): Air Platform, Sensors, Weapons

ACQUISITION PROGRAM: ONR Hypersonics D&I Program

OBJECTIVE: Develop and demonstrate non-intrusive diagnostics to: (1) quantify the spatiotemporal evolution of raindrops, ice crystals (clouds), and snow during high-speed aerobreakup; and (2) simultaneously quantify aerobreakup effects on the surrounding gas parameters such as velocity, composition, and thermodynamic state variables.

DESCRIPTION: The effect of adverse weather on hypersonic flight conditions is not well understood. Hydrometeors such as rain, hail, snow, and ice disrupt the flow field and impinge on the vehicle surface. Because the impact forces approximately scale as the velocity squared, hypersonic vehicles are at greater risk of damage [Ref

1]. The modeling and understanding of weather encounters are challenging because the vehicle flow field alters the impact boundary conditions as a function of time. Since existing computational models cannot capture these complex, multiscale finite-rate processes, weather effects are currently estimated via component testing and empirically derived correlations.

At altitudes below 4 km, rain is the most prevalent weather encounter. When raindrops are suddenly exposed to a high-speed gas flow, they deform and shatter due to shear-induced entrainment and/or interfacial flow instabilities. This phenomenon, known as aerobreakup, increases in intensity with Weber number. Aerobreakup experiments have typically been performed in shock tubes at moderate supersonic Mach numbers, $M < 2$. With the exception of recent laser-induced florescence (LIF) measurements [Ref 2], aerobreakup measurements strictly use path-integrated visualization techniques that have led to erroneous physical interpretations [Ref 3]. Weather effects are not limited to low-altitude flight since clouds such as cumulonimbus can reach altitudes exceeding 20 km. Prolonged exposure to high-altitude solid hydrometeors can produce surface roughness that initiate the flow instabilities responsible for laminar-turbulent boundary layer transition.

The development of improved numerical tools requires validation against high-quality experimental data that captures both the spatiotemporal evolution of the hydrometeors during aerobreakup and the effect of the aerobreakup on the surrounding flow field. Such measurements are currently unavailable in ground-test facilities due to the lack of advanced non-intrusive diagnostics. Recent advances in instrumentation and measurement techniques such as high-speed intensified camera, tunable pulsed-burst lasers, and tomographic reconstruction algorithms [Refs 4-7] can be leveraged to develop improved instrumentation for quantitative assessment of weather effects on high-speed flows. Four-Dimensional X-ray imaging [Ref 8] recently used to study an optically complex spray seems promising to provide measurements of droplet structures and liquid density in the near field.

KEY REQUIREMENTS OF THE INSTRUMENTATION SUITE AND PARAMETERS:
• The non-intrusive instrument (or suite of instruments) needs to provide three-dimensional, time-resolved measurements of the aerobreakup process including the atomization of small droplets.
• The non-intrusive instrument (or suite of instruments) needs to provide gas phase measurements (velocity, state variables and composition) for freestream Mach numbers above 3 and conditions corresponding to altitudes below 4 km for raindrops and up to 20 km for ice crystals (present in clouds).
• Primary droplet diameters of approximately 0.3 to 3 mm and secondary droplet diameters of 0.03 to 0.2 mm need to be resolved by the instruments. Ice crystals can be significantly smaller (1 to 50 microns). Therefore, the instrument suites must provide an adequate range of magnifications and spatial resolutions to resolve the wide range of relevant spatial scales.
• Ideally, the instrument must be suitable for measurements with solid particles used as surrogates for hydrometeors (with diameters between 0.03 and 3 mm).
• The non-intrusive instrument (or suite of instruments) needs to operate in various types of large-scale ground-test facilities such as shock tubes, ballistic ranges (light-gas gun), and wind tunnels.
• Ideally, the non-intrusive instrument (or suite of instruments) must be portable (on a cart or set of carts) for usage in multiple facilities.

PHASE I: Design a non-intrusive instrument or a suite of non-intrusive instruments to quantify the spatiotemporal evolution (three-dimensional, time-resolved measurements) of raindrops, ice crystals (clouds), and snow during high-speed aerobreakup, and concurrently quantify aerobreakup effects on the surrounding gas. (Note: Preferably, benchtop demonstrations of the instrument concepts shall occur in a shock tube or other facilities producing a relevant environment.) Develop a Phase II plan.

PHASE II: Refine and optimize the instrument and/or suite to produce a viable prototype. Demonstrate the performance of the prototype in a relevant ground test facility such as a ballistic range (light-gas gun), wind tunnel, or shock tube. Produce relevant data to quantify the spatiotemporal evolution of raindrops, ice crystals (clouds), and snow during high-speed aerobreakup and the effect of the aerobreakup on the surrounding gas. Assess interactions with single and multiple droplets (corresponding to relevant precipitation rates).

PHASE III DUAL USE APPLICATIONS: Private companies have demonstrated interest in commercial hypersonic flight. It will be important to assess the impact of weather effects on commercial systems. The developed instrumentation suite could be used in high-speed ground test facilities operated by the commercial sector.

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KEYWORDS: Weather Effects; Multiphase Flows; Laser Diagnostics; Tomography; Hypersonics; High-speed Flows; Ground Test

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N20A-T021 TITLE: Hybrid Packaging of Cryogenic Electronics and Photonic Technologies

TECHNOLOGY AREA(S): Electronics, Information Systems, Sensors

ACQUISITION PROGRAM: IARPA Super Cables and ongoing Darpa MTO whole wafer Multichip modules programs, and CSTG4

OBJECTIVE: The objective of this effort is to originate and begin to mature a scalable heterogeneous packaging plan which results in extreme energy efficiency information transfer at high clock rates and low bit error rate of digital data between superconducting and photonic technologies, each at 4K, in a mechanically robust package that withstands repeated thermal cycling from 300K without performance degradation.

DESCRIPTION: Photonic interconnect has become the dominant technology for long-haul data networks, due to its unmatched distance bandwidth product. As data rates continue to increase, photonic interconnect is being incorporated into room temperature data networks within the equipment racks and even into the multi-chip module packages. This success strongly suggests considering using photonics to move the data created by cryogenic digitizers and sensors up to room temperature and into commercial off-the-shelf (COTS) processors. However, in order for photonic interconnects to become the dominant technology for this application, substantial issues must be addressed. These include the requirements for extreme energy efficiency in getting photons on and off the 4K photonic integrated circuit (PIC) chip and for packaging compatibility with the cryogenic electrically based Very-large-scale integration (VLSI) chips, most of which are based on some form of superconducting device. Most of these superconducting circuits also require magnetic shielding and most shields work by fully encapsulating the circuits, leaving little access for quite rigid and fragile fibers. Moreover, because the power levels required by silicon complementary metal-oxide semiconductor (CMOS) are 4 orders of magnitude larger than needed by niobium digital devices, photonic noise issues that are not problematic at room temperature may have to be addressed when the signal power is drastically reduced, as must occur for low temperature use. Moreover, high frequency circuit operations are a hallmark advantage of superconducting electronics. Thus the packaging that allows transfer of such high speed signals to the PIC requires intimate contact in the photonic to electrical bump bonds to be developed.

Today at 4K isothermal electrical data transport is fully reliable at serial rates above 100 Gbps when the signal path stays on the same chip or moves to an adjacent one through bump bonds and wiring on a Si multi-chip module. The energy cost of such transfer is measured in the aJ/bit. However, electrical data connections between a cryogenic (4K) receiver or processor and one at room temperature introduce significant parasitic heat loads (up to 30mW for 3 bit 40Gps, low BER data flow) given the 4 to 300K thermal gradient and the fundamental physics that connects thermal and electrical conductivity. Thus, the Office of Naval Research (ONR) and the Intelligence Advanced Research Projects Activity (IARPA) are working on high energy efficiency electro-optical modulators/lasers to replace these electrical conductors with optical links. But for them to be successful, the required co-packaging should be considered from the onset, not attempted only at the end. That is the goal of this topic. In future large-scale superconducting circuits, it is already clear the functional blocks will be fabricated on individual chips and those chips pretested. The successful ones will then be flip chip bonded face down on Si multi-chip modules (MCM) which are expected to grow to 300 mm diameter. To function properly, each of the superconducting chips needs to exist where there is a net magnetic field under 4 micro-T in strength. This field will be the sum of the external environmental field (e.g., Earth's) and those generated by currents internal to the vacuum vessel, such as those of the power lines feeding the circuits. To date, that shielding is created passively by closed shields of high permativity magnetic materials around each superconducting processing chip. Thus when providing photonic data links, it is critical to consider the photonic access to the circuits within the magnetic shields as well as to reduce the optical losses in the fiber to waveguide connections. (Any scattered photons will contribute to the parasitic heat load which must be less than the electrical one for photonics to be competitive compared to all electrical data link solutions.)

For small electronics assemblies, it may be feasible to electrically conduct the digital results to the outside edges of the MCM and from there into a specific electro-optical (EO) conversion chip that then launches the light into a fiber. Grating couplers use vertical access for the fiber paths, which may well maximize the chance of breakage in a large area/number of fibers assembly, and currently have about 1 dB of insertion loss. Permanently attached, taped fibers potentially offer lower insertion loss if their movement during epoxy curing, tendency for irreproducible coupling performance, and extreme fragility can be resolved. Both of these methods have problems during cool down with shifting of the alignment of the fiber core with a PIC waveguide. Alignment of arrayed edge couplers after cooling may be more appealing because the planarity of the array can match the array of waveguide inputs. However, no reliable method for optimizing the cold alignment has been invented. Moreover, how this method could scale is totally undefined since the interior superconducting chips currently lack any exposed edges and any mounting areas for attocube-like fiber array aligners.

In all cases, the threshold photonic insertion loss tolerable is 0.2 dB at data rates of 40 Gbps and the goal is to reach below 0.1 dB. The optical alignment and attachment procedures must be robust against thermal cycling (a minimum of 2,000 thermal cycles between 300 to 4K) and vibration of the entire assembly, whether arising from the motion of the deployment platform or created by the periodic motion of a piston within the cryo-cooler compressor. The ability to scale to whole wafer scales and accommodate an arbitrary ratio of superconducting processor area to the numbers of photonic cable leads is desirable. The Navy envisions eventual compatibility with a system geometry where MCM are treated as circuit cards. In this imagination, each MCM is attached on one edge to a thermal bus and staggered about the axis in a deck of card geometry. The perpendicular distance between MCM "cards" must be minimized if the total system density is to be high. How the fibers can attach is then even less clear. Such future enhancements should be compatible with near term choices for the MCM geometry. Phase I proposals must define a plan of attack to demonstrate a packaging strategy for data transmission between a cryogenic superconducting digital integrated circuit (IC) and a room temperature environment. Proposers should clarify the blend of work on total/local magnetic shields versus low loss optical fiber attachment and alignment, all in an MCM context. All blends ranging from 100/0 to 0/100 are acceptable in Phase I. Both sides of this problem must have been worked by the end of Phase II, possibly via a merger of funded efforts in Phase II. A clear Gannt chart of the proposed Phase I Base and Option tasks is essential and should indicate whether the company or non-profit is responsible for each task. Discussion of test plans is desirable. Any need for government furnished property (GFP) should be carefully noted in the proposal.

PHASE I: The Phase I base effort needs to work the efforts defined in the original proposal so as to significantly lower the risk of success if a follow--on award is offered. The provisional Phase II plan delivered at the end of the Base period will determine whether each performer wins a Phase II. If selected, the Phase I Option will then be awarded. It should provide continuity until the Phase II begins and further reduce technical risk of the proposed overall approach. For performers working only one side of the technology in Phase I, Phase II must contain a plan to add the other.

PHASE II: In the Phase II Base period, design, build, and demonstrate a working assembly consisting of a photonically connected (e.g., to the outside world) superconducting MCM at least 10 x 10 mm (preferably larger) in area and having at least 2 distinct magnetically shielded superconducting chips and 2 photonic input/output (IO) links to the MCM. Some interdependence of the functionality of the 2 technologies needs to be demonstrated (e.g., a fiber provides an activation signal to the superconducting chip and its measurement result is conveyed over fiber to room temperature). The insertion losses and heat loads of the design should be quantified by the end of the Base effort. The first Option, if exercised, should further reduce the technical risk to the system performance of the approach taken.

PHASE III DUAL USE APPLICATIONS: As photonic interconnects become the norm at room temperature in data centers and other computationally dense platforms, they need a way to connect without waveform distortion ("robustly") with electronics chips. Even if the systems are run near room temperature, many of the issues are common with those in this STTR topic. These include the need to fit into 3D packages (with no large empty area over the chips, densely placed face down packaging to attach to bump bonds), discrepant wiring line widths/photonic mode diameters, and differential thermal contraction during thermal cycling. Thus, the work in this effort is expected to have applicability in commercial room temperature settings, e.g., within data centers. At low temperatures, success in programs such as IARPA's Super Cables could make sensor array readout for astro-physics and particle physics, where FDM is already the norm, another possible application area. Within the Government, the interests are primarily centered around high-performance computing and radio frequency (RF) digital signal processing. As a subset of the latter, the ability to do analog signal processing within 4K digital receivers is an attractive possibility. Most of these applications are long term, compatible with the philosophy of the STTR program.

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KEYWORDS: Magnetic Shielding; Flip Chip Bonding; Minimal Insertion Loss; Multi-chip Modules; Fiber to Photonic Wave Guide Launches; Coefficient of Thermal Expansion

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N20A-T022 TITLE: Measurements of Wall-Shear-Stress Distribution in Hypersonic Flows

TECHNOLOGY AREA(S): Air Platform, Sensors, Weapons

ACQUISITION PROGRAM: ONR Hypersonics D&I Program

OBJECTIVE: Develop, calibrate, and demonstrate a non-intrusive method to measure wall-shear-stress distributions in hypersonic ground test facilities.

DESCRIPTION: The ability to accurately predict the state of boundary layers and regions of separated flows is a key consideration for the design of hypersonic vehicles [Ref 1]. The state of the boundary layer affects the surface skin friction, which, when integrated, impacts predictions of flight performance through lift, drag, and moment coefficients [Ref 1]. In addition, flow separation influences the effectiveness of control surfaces and consequently the vehicle control authority. Therefore, accurate measurements of wall-shear-stress are paramount to predicting the characteristics of boundary layers and the performance of hypersonic vehicles. In addition, the availability of wall-shear-stress distribution measurements in hypersonic ground test facilities is highly valuable to improve and validate the computational tools needed to extrapolate ground test measurements to flight conditions.

Reliable sensors suitable for large-scale hypersonic ground test facilities have been developed and demonstrated over recent years for one-[Ref 2] and two-component wall-shear-stress measurements [Ref 3]. However, to obtain two-dimensional surface information using traditional sensors, one must use a large number of point-measurements that are individually attached/machined onto the surface. This process can be time-consuming and expensive. Ultimately, the number of sensors employed limits the spatial resolution of shear stress data, thereby limiting the usefulness of sensor data for complex flow fields. Oil flow visualization [Ref 4] is useful in obtaining near-wall streamlines, but cannot provide quantitative values of the skin-friction distribution. Quantitative methods such as shear-sensitive liquid crystals have been applied in high-speed flows [Ref 5], but its suitability for hypersonic wind tunnels remains uncertain because of spurious inputs due to variations in surface temperatures. This STTR topic is seeking a technique to quantitatively measure the skin friction distribution on the surface of hypersonic wind tunnel test articles.

KEY REQUIREMENTS
• Provides 2D measurements of the skin-friction distribution (magnitude and direction)
• Non-intrusive technique compatible with standard hypersonic wind tunnel test articles such as a sensing coating that can be applied on the surface
• Allows measurement on smooth curved surfaces (such as conical geometries)
• Spatial resolution better than or equal to 5 mm x 5 mm
• Temporal resolution greater than or equal to 1 kHz
• Wide dynamic range and high sensitivity to allow simultaneous measurements in regions of high shear (shear-stress magnitude ~ 250 Pa) and regions of separated flows (zero shear-stress or low magnitude with reversed direction)
• Intrinsic insensitivity to spurious inputs such as surface temperature and pressure or accurate correction of spurious inputs via calibration and/or input measurements

PHASE I: Develop a methodology for measuring the wall-shear-stress distribution at Mach 5 or above and surface temperatures up to 395K or above. Demonstrate the suitability of the measurement technique via benchtop experiments. Develop concepts for calibration and characterization of sensitivity to spurious inputs such as pressure and temperature. Develop a Phase II plan.

PHASE II: Further develop the methodology for measuring wall-shear-stress distribution globally and instantaneously at Mach 5-7 and surface temperatures up to 493K or above on canonical geometries such as flat plates and cones. Develop and validate a calibration methodology and characterize sensitivity due to extraneous inputs such as temperature and pressure. Validate measurements by comparing results with theory and previously published results. Validate the global measurements with several discrete shear stress sensors situated along the centerline or ray of a flat plate or cone. By the end of Phase II, the technology should be TRL 5.

PHASE III DUAL USE APPLICATIONS: Further refine the measurement technology to increase the accuracy, range of conditions to higher Mach numbers, and dynamic pressures. Develop commercial system that can be marketed and deployed in large-scale ground test facilities operated by commercial space and aviation companies and the Federal Government.

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KEYWORDS: Hypersonic Flow; Wall-shear-stress Distribution; Ground Testing; Non-intrusive; Diagnostics; High-speed

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N20A-T023 TITLE: Harvesting Thermal Energy for Low Power Arctic Sensors and Data Communications

TECHNOLOGY AREA(S): Battlespace, Sensors

ACQUISITION PROGRAM: Arctic Mobile Observing System (AMOS) Innovative Naval Prototype (INP)

OBJECTIVE: Develop a survivable capability to harness the Arctic Ocean/Air thermal gradient and provide low power for persistent unmanned Arctic sensors and data communications via Arctic Ocean buoys.

DESCRIPTION: The Navy runs environmental models to provide forecasts for operational use in the Arctic region. The Navy continues to invest in improved predictive capabilities for the Arctic region that will enable more skillful forecasts from weeks to months. A key challenge to modeling the Arctic is the lack of meteorological and oceanographic observational data. Improvements in environmental characterization and predicative capabilities will depend on increasing measurements of the region [Ref 1].

As the Navy continues to implement a persistent unmanned presence in the Arctic Ocean to achieve observational goals, new methods to generate power on site are required in order to sense the environment and communicate data for assimilation into operational models. Currently, unmanned Arctic buoys and platforms carry batteries that take up weight and volume. Power generation via solar and wind energy is available but compromised in the Arctic due limited sunlight hours and harsh winds that require large, expensive structures for survivability. Developing an innovative capability that uses the thermal gradient between Arctic Air and Ocean to generate in-situ power will allow the Navy to harvest an existing energy resource and improve persistence of observations in the region.

Thermal gradients between air and ocean surfaces in the Arctic, expressed as temperature differences and heat flow, can be directly converted into electrical energy [Ref 2]. While there are many factors that affect the entire Arctic Energy Budget, air temperature is a measure of the amount of energy held in the air, while ocean surface temperature is a measure of the amount of solar energy absorbed or reflected in the upper surface. Arctic air temperatures vary widely from -50 to 32°C while Arctic Ocean surface temperatures vary less with yearly averages between -1.8 to 3°C [Ref 3]. These thermal gradients are adequate to generate low power levels.

The Navy seeks an innovative prototype solution to harvest Arctic Ocean thermal energy in-situ and provide low power levels to sensors and data communications while integrated onto a free floating or ice-tethered Arctic buoy such as an Autonomous Arctic Ocean Flux Buoy (AFOB) or Ice Tethered Arctic Profiling Buoy. The planned energy persistence level is one year for low power environmental and oceanographic observational sensors as well as gateway buoy data communications. The desired performance is a 500W thermal harvesting system that can be incorporated into a standard Arctic oceanographic buoy and potentially in a configuration that is moored to the ice. The highest performance risk is the survivability of the energy generator in the harsh Arctic environment. The highest known technical risk is addressing the energy efficiency of generating power given the relatively low thermal gradient that exists on a daily average in the Arctic.

PHASE I: Define and develop a concept for a prototype that can meet the performance and technical requirements listed in the Description. Determine optimal locations and approach for integration and deployment of the prototype onto an Arctic buoy platform. Develop a Phase II plan.

Note: An Oceanographic Research Institute can contribute to all phases of this research. Oceanographers familiar with the Arctic can inform the team about ocean circulation, temperature-salinity environments, currents, winds and other environmental factors that the innovative prototype will need to address. Oceanographers can provide specific power loads required from environmental and oceanographic sensors and data communications.

PHASE II: Construct a prototype using the expertise of research institute ocean engineers to inform the team of valuable lessons learned from previous Arctic platforms, which will drive down technical and performance risk.

PHASE III DUAL USE APPLICATIONS: Integrate the Phase II prototype onto an Arctic buoy that will be deployed in September of 2022 as part of the Arctic Mobile Observing System (AMOS) Innovative Naval Prototype program. During Phase III, research institution technicians can provide invaluable insight about deploying a research prototype in the Arctic.

Dual use applications for this system would include commercial and non-DoD maritime needs such as ROV operations for the Oil and Gas Industry and non-DoD navigation and environmental monitoring in remote locations.

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KEYWORDS: Thermal Energy Generation; Low Power for Sensors; Arctic Sensors; Arctic Mobile Observing System; Thermoelectric Generator; Persistent Sensing

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N20A-T024 TITLE: Scenario Data Solutions for Forward Deployed Live, Virtual, and Constructive Training at Sea

TECHNOLOGY AREA(S): Human Systems

ACQUISITION PROGRAM: Fleet Training Wholeness Continuum (FTWC) and Total Ship's Training Concept (TSTC)

OBJECTIVE: Develop shore-based capabilities to improve mission warfighter mission readiness against Great Power Competitors (GPC) and to increase warfare proficiency and agility while operating in a degraded and denied environment against GPC.

DESCRIPTION: Currently, the Navy employs large numbers of at sea mentors, assessors, and certifiers, using a "White Cards" technique to inject a description of the degraded or denied effects on command and control (C2) systems. This is done because the actual distributed simulation of the degraded or denied (D2) effects on the at-sea ships and aircraft C2 systems cuts off the two-way communications between the shore distributed training center (DTC) and the mentors, assessors, and certifiers at sea. This "White Card" method of simulation, or lack of actual effects to the C2 systems, provides "Negative Training" and degrades warfighter readiness. Some specific issues that the technologies the Navy is seeking could address include smart/intelligent communication/simulation routing, and communication/simulation compression over existing communication circuits. The additional benefit from these sought technologies might be to daily operational and tactical operations when the Fleet is being challenged by GPC in a real-world command and control, degraded and denied environment (C2D2E).

PHASE I: Create a concept for software/hardware that design an information assured (IA) NSA approved two-way transmission of simulation and mentor information via a single circuit while all other circuits are being degraded and/or denied. Ensure that the D2 environment does not affect the simulation and mentor information path between the simulation distribution site and shore-based replicate at-sea node. The proof of concept should demonstrate a shore site replicating a DTC and a node replicating a shipboard training suite, transmitting simulation and mentor data being passed two-way without any degradation or loss of data. Develop a Phase II plan.

PHASE II: Build and test a usable prototype of the software/hardware to be tested between a shore site replicating a DTC and a ship pierside using actual Navy C2 circuits. Test the prototype in a simulation on the ship that will be of a degraded and denied environment (D2E) that affects major operational/tactical circuits while non-D2 mentor data are transmitted two-ways. The two-way mentor data will not be degraded. The mentor and simulation data will be degraded between "10 to 15 percent". Naval Simulation Center Pacific (NSCPAC), San Diego, CA with Tactical Training Group Pacific (TTGP) will act as the DTC and a suitable Destroyer will be assigned by the Surface TYCOM Command Naval Surface Forces – Pacific (CNSF) to execute this test.

PHASE III DUAL USE APPLICATIONS: Refine the prototype as necessary and make the technology available to the Navy. The technology(ies) will be installed at TTGP and onboard an assigned Destroyer at sea during a Live, Virtual, and Constructive (LVC) Composite Training Unit Exercise (COMPTUEX) offshore on the West Coast Tactical Training Range (WCTTR). Use of these technologies will help inform the Navy Fleet Training Program on how to use Operational/Tactical circuits to transport simulation and mentor data while at sea.

Potential commercial uses for securing Commercial/DoD Cloud Storage, improving network data transferring, improving mixed data transmission across low bandwidth networks, strong data security across commercial wireless networks, and real-time reachback support for technicians in the field across low bandwidth networks.

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KEYWORDS: Live; Virtual and Constructive (LVC); Fleet Synthetic Training (FST); Fleet Synthetic Training (FST) at Sea (FAS); Navy Training

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N20A-T025 TITLE: Post Digitizer Analog to Digital Converter (ADC) Linearization Using Artificial Intelligence Methods

TECHNOLOGY AREA(S): Electronics, Information Systems, Sensors

ACQUISITION PROGRAM: ESM and SIGINT 6.3a program are target audience

OBJECTIVE: Increase the analog to digital convertor (ADC) Spurious-free Dynamic Range (SFDR) by 10 dB by digitally diminishing the predictable spurs. Wideband Si and SiGe ADCs often incorporate substantial on-chip linearization processing. In contrast, superconducting ADCs are not today linearized and exhibit spurs as large as 15 dB above the inherent quantization noise floor.

DESCRIPTION: This STTR topic requires a deep understanding of the nature of quantization errors in low bit count, high-speed digitizers and the interdependence of time and frequency domain signal representations. However, no details of the exact ADC will be provided and no run-time dynamic adaptation of the circuit will be acceptable. Rather proposers are expected to correct the output data stream in real time using only digital processors. Two types of distortions of the frequency domain output of ADCs are of concern: a) fixed subharmonics of the sampling clock engendered by rapid switching transients in the output drivers weakly (~-30 dB down) coupled to the analog signal inputs; and b) harmonics of the signal fundamentals, some of which reflect the actual quantization errors associated with the limited bit width samples. The topic philosophy is that the clock spurs are at entirely predictable and consistent frequencies. While their relative amplitudes might depend on the signal mix being digitized at any given time, that will change relatively slowly and some form of interference cancellation/background subtraction ought to be applicable. Achieving that should be the first goal of the effort. Then in the 3 bit, 40 GSps ADCs of greatest interest, there is a range of signal amplitudes where a Fourier Transform shows as many as 18 harmonics above the quantization noise floor, but not any other mixing products (e.g., with the clock). It is for a smaller signal amplitude range such that maybe only 5 harmonics break the noise floor that the second goal applies. Namely, these harmonics in part reflect the inaccuracies of the real quantization levels in comparison to the actual time dependent signal shape and in part systematic errors in the threshold levels compared to their optimal selection. As such, constructively using the harmonic signals observed ought to provide a way of making the signal representation output more accurate. The real thermal noise that is being quantitized must be distinguished from these systematic terms but is expected to be a small contribution to the total spur power. Recorded data of an actual ADC's response to various amplitude and frequency sine waves can be provided as government furnished information (GFI) for software training purposes if the proposer so requests. Artificial intelligence (AI) and machine learning (ML) are assumed to be the sources of potential solutions due to their ability to learn systematic behavior without supervision. However, any other approach capable of keeping up with the ADC results arrival rate may be proposed. Processing latencies of less than 1 millisecond and reduction of the effective spurs by more than 6 dB are sought.

PHASE I: In the Phase I proposal, define a definite plan of attack to be conducted and clarify the balance between proposed tasks. The proposal should also define a mechanism for selecting the more successful one if more than one approach is to be attempted, include a clear Gannt chart of the proposed tasks, and indicate whether the contractor or sub-contractor is responsible for each task. Inclusion of a discussion of test plans is desirable. Any need for GFI and its data ingest format should also be carefully described. The Phase I Base effort needs to work the concepts/tasks defined in the original proposal so as to significantly lower the risk of success if a follow-on award is offered. The preliminary Phase II proposal delivered at the end of the Base effort will be used to select the Phase II winner. The Phase I Option should be structured to further lower the technical risk of Phase II assuming the approach of the Base succeeds. If any approaches prove unworkable, the topic author(s) should be consulted before the approach is changed. The provisional Phase II plan delivered at the end of the base Phase I Base period will determine whether each performer is awarded a Phase II contract. If selected for Phase II, the Phase I Option period will then be exercised. It should provide continuity until the Phase II begins and further reduce technical risk of the proposed overall approach. Phase II is when the claim of real time processing needs to be developed/demonstrated.

PHASE II: Conduct a working experimental demonstration of spectral clean up by the developed signal processing in the labs of the Government or the ADC vendor to demonstrate real-time processing. Quantification of the degree of real-time spur reduction achieved as a function of sampling clock frequency is expected. The Government will help arrange that testing late in the Phase I Base period.

PHASE III DUAL USE APPLICATIONS: By the end of this STTR effort, the ADC in question ought to have transitioned into fielded systems. Hence once this software is proven useful, it can be added into the digital signal processing (DSP) portion of such systems and result in higher accuracy situational awareness reports to the warfighter. Outside the DoD, the resultant software is expected to be the first linearization product that directly addresses frequency domain issues following a time domain digitizer and could be one of the earliest systems to combine AI with ML in a hybrid, directed system architecture. Examples in other application domains, including correcting for amplifier distortion, ought also to be possible. Specific commercial markets could include satellite communications and many band 5G wireless networks in addition to laboratory instrumentation.

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