

VERSION 4

DEPARTMENT OF THE NAVY (DON) 22.A Small Business Technology Transfer (STTR) Proposal Submission Instructions

IMPORTANT

- **The following instructions apply to STTR topics only:**
 - N22A-T001 through N22A-T026
- **The information provided in the DON Proposal Submission Instructions document takes precedence over the DoD Instructions posted for this Broad Agency Announcement (BAA).**
- **DON Phase I Technical Volume (Volume 2) page limit is not to exceed 10 pages.**
- Phase I Technical Volume (Volume 2) and Supporting Documents (Volume 5) templates, specific to DON topics, are available at https://www.navysbir.com/links_forms.htm.
- The DON provides notice that Basic Ordering Agreements (BOAs) may be used for Phase I awards, and BOAs or Other Transaction Agreements (OTAs) may be used for Phase II awards.

INTRODUCTION

The DON SBIR/STTR Programs are mission-oriented programs that integrate the needs and requirements of the DON's Fleet through research and development (R&D) topics that have dual-use potential, but primarily address the needs of the DON. More information on the programs can be found on the DON SBIR/STTR website at www.navysbir.com. Additional information on DON's mission can be found on the DON website at www.navy.mil.

Digital Engineering. DON desires the ability to design, integrate, and test naval products by using authoritative sources of system data, which enables the creation of virtual or digital models for learning and experimentation, to fully integrate and test actual systems or components of systems across disciplines to support lifecycle activities from concept through disposal. To achieve this, digital engineering innovations will be sought in topics with titles leading with DIGITAL ENGINEERING.

The Program Manager of the DON STTR Program is Mr. Steve Sullivan. For questions regarding this BAA, use the information in Table 1 to determine who to contact for what types of questions.

TABLE 1: POINTS OF CONTACT FOR QUESTIONS REGARDING THIS BAA

Type of Question	When	Contact Information
Program and administrative	Always	Program Managers list in Table 2 (below)
Topic-specific technical questions	BAA Pre-release	Technical Point of Contact (TPOC) listed in each topic. Refer to the Proposal Fundamentals section of the DoD SBIR/STTR Program BAA for details.
	BAA Open	DoD SBIR/STTR Topic Q&A platform (https://www.dodsbirsttr.mil/submissions)

VERSION 4

		Refer to the Proposal Fundamentals section of the DoD SBIR/STTR Program BAA for details.
Electronic submission to the DoD SBIR/STTR Innovation Portal (DSIP)	Always	DoD Help Desk via email at dodsbirsupport@reisystems.com
Navy-specific BAA instructions and forms	Always	Navy-sbir-sttr.fct@navy.mil

TABLE 2: DON SYSTEMS COMMANDS (SYSCOM) SBIR PROGRAM MANAGERS

<u>Topic Numbers</u>	<u>Point of Contact</u>	<u>SYSCOM</u>	<u>Email</u>
N22A-T001 to N22A-T008	Mr. Shawn Slade (Acting)	Naval Air Systems Command (NAVAIR)	navair.sbir@navy.mil
N22A-T009 to N22A-T015	Mr. Jason Schroeffer	Naval Sea Systems Command (NAVSEA)	NSSC_SBIR.fct@navy.mil
N22A-T016 to N22A-T026	Mr. Steve Sullivan	Office of Naval Research (ONR)	onr-sbir-sttr.fct@navy.mil

PHASE I SUBMISSION INSTRUCTIONS

The following section details what is required for a Phase I proposal submission to the DoD SBIR/STTR Programs.

(NOTE: Proposers are advised that support contract personnel will be used to carry out administrative functions and may have access to proposals, contract award documents, contract deliverables, and reports. All support contract personnel are bound by appropriate non-disclosure agreements.)

DoD SBIR/STTR Innovation Portal (DSIP). Proposers are required to submit proposals via the DoD SBIR/STTR Innovation Portal (DSIP); follow proposal submission instructions in the DoD SBIR/STTR Program BAA on the DSIP at <https://www.dodsbirsttr.mil/submissions>. Proposals submitted by any other means will be disregarded. Proposers submitting through DSIP for the first time will be asked to register. It is recommended that firms register as soon as possible upon identification of a proposal opportunity to avoid delays in the proposal submission process. Proposals that are not successfully certified electronically in DSIP by the Corporate Official prior to BAA Close will NOT be considered submitted and will not be evaluated by DON. Please refer to the DoD SBIR/STTR Program BAA for further information.

Proposal Volumes. The following six volumes are required.

- **Proposal Cover Sheet (Volume 1).** As specified in DoD SBIR/STTR Program BAA.
- **Technical Proposal (Volume 2)**
 - Technical Proposal (Volume 2) must meet the following requirements or it will be REJECTED:
 - Not to exceed 10 pages, regardless of page content
 - Single column format, single-spaced typed lines

VERSION 4

- Standard 8 ½” x 11” paper
- Page margins one inch on all sides. A header and footer may be included in the one-inch margin.
- No font size smaller than 10-point
- Include, within the 10-page limit of Volume 2, an Option that furthers the effort in preparation for Phase II and will bridge the funding gap between the end of Phase I and the start of Phase II. Tasks for both the Phase I Base and the Phase I Option must be clearly identified. Phase I Options are exercised upon selection for Phase II.
- Phase I Base Period of Performance must be exactly six (6) months.
- Phase I Option Period of Performance must be exactly six (6) months.
- Additional information:
 - It is highly recommended that proposers use the Phase I proposal template, specific to DON topics, at https://navysbir.com/links_forms.htm to meet Phase I Technical Volume (Volume 2) requirements.
 - A font size smaller than 10-point is allowable for headers, footers, imbedded tables, figures, images, or graphics that include text. However, proposers are cautioned that if the text is too small to be legible it will not be evaluated.
- **Cost Volume (Volume 3).**
 - Cost Volume (Volume 3) must meet the following requirements or it will be REJECTED:
 - The Phase I Base amount must not exceed \$140,000.
 - Phase I Option amount must not exceed \$100,000.
 - Costs for the Base and Option must be separated and clearly identified on the Proposal Cover Sheet (Volume 1) and in Volume 3.
 - For Phase I a minimum of 40% of the work is performed by the proposing firm, and a minimum of 30% of the work is performed by the single research institution. The percentage of work is measured by both direct and indirect costs. To calculate the minimum percentage of effort for the proposing firm the sum of all direct and indirect costs attributable to the proposing firm represent the numerator and the total proposals costs (i.e., costs before profit or fee) is the denominator. The single research institution percentage is calculated by taking the sum of all costs attributable to the single research institution as the numerator and the total proposal costs (i.e., costs before profit or fee) as the denominator.
 - Additional information:
 - Provide sufficient detail for subcontractor, material, and travel costs. Subcontractor costs must be detailed to the same level as the prime contractor. Material costs must include a listing of items and cost per item. Travel costs must include the purpose of the trip, number of trips, location, length of trip, and number of personnel.
 - Inclusion of cost estimates for travel to the sponsoring SYSCOM’s facility for one day of meetings is recommended for all proposals.
 - The “Additional Cost Information” of Supporting Documents (Volume 5) may be used to provide supporting cost details for Volume 3. When a proposal is selected for award, be prepared to submit further documentation to the SYSCOM Contracting Officer to substantiate costs (e.g., an explanation of cost estimates for equipment, materials, and consultants or subcontractors).
- **Company Commercialization Report (Volume 4).** DoD collects and uses Volume 4 and DSIP requires Volume 4 for proposal submission. Please refer to the Phase I Proposal section of the DoD SBIR/STTR Program BAA for details to ensure compliance with DSIP Volume 4 requirements.

VERSION 4

- **Supporting Documents (Volume 5).** Volume 5 is for the submission of administrative material that DON may or will require to process a proposal, if selected, for contract award. All proposers must review and submit the following items, as applicable:
 - **Telecommunications Equipment Certification.** Required for all proposers. The DoD must comply with Section 889(a)(1)(B) of the FY2019 National Defense Authorization Act (NDAA) and is working to reduce or eliminate contracts, or extending or renewing a contract with an entity that uses any equipment, system, or service that uses covered telecommunications equipment or services as a substantial or essential component of any system, or as critical technology as part of any system. As such, all proposers must include as a part of their submission a written certification in response to the clauses (DFAR clauses 252.204-7016, 252.204-7018, and subpart 204.21). The written certification can be found in Attachment 1 of the DoD SBIR/STTR Program BAA. This certification must be signed by the authorized company representative and is to be uploaded as a separate PDF file in Volume 5. Failure to submit the required certification as a part of the proposal submission process will be cause for rejection of the proposal submission without evaluation. Please refer to the instructions provided in the Phase I Proposal section of the DoD SBIR/STTR Program BAA.
 - **Disclosure of Offeror's Ownership or Control by a Foreign Government.** All proposers must review to determine applicability. In accordance with DFARS provision 252.209-7002, a proposer is required to disclose any interest a foreign government has in the proposer when that interest constitutes control by foreign government. All proposers must review the Foreign Ownership or Control Disclosure information to determine applicability. If applicable, an authorized firm representative must complete the Disclosure of Offeror's Ownership or Control by a Foreign Government (found in Attachment 2 of the DoD SBIR/STTR Program BAA) and upload as a separate PDF file in Volume 5. Please refer to instructions provided in the Phase I Proposal section of the DoD SBIR/STTR Program BAA.
 - Additional information:
 - Proposers may include the following administrative materials in Supporting Documents (Volume 5); a template is available at https://navysbir.com/links_forms.htm to provide guidance on optional material the proposer may want to include in Volume 5:
 - Additional Cost Information to support the Cost Volume (Volume 3)
 - SBIR/STTR Funding Agreement Certification
 - Data Rights Assertion
 - Allocation of Rights between Prime and Subcontractor
 - Disclosure of Information (DFARS 252.204-7000)
 - Prior, Current, or Pending Support of Similar Proposals or Awards
 - Foreign Citizens
 - Do not include documents or information to substantiate the Technical Volume (Volume 2) (e.g., resumes, test data, technical reports, or publications). Such documents or information will not be considered.
 - A font size smaller than 10-point is allowable for documents in Volume 5; however, proposers are cautioned that the text may be unreadable.
- **Fraud, Waste and Abuse Training Certification (Volume 6).** DoD requires Volume 6 for submission. Please refer to the Phase I Proposal section of the DoD SBIR/STTR Program BAA for details.

VERSION 4

PHASE I EVALUATION AND SELECTION

The following section details how the DON SBIR/STTR Programs will evaluate Phase I proposals.

Proposals meeting DoD SBIR/STTR submission requirements will be forwarded to the DON SBIR/STTR Programs for evaluation. Prior to evaluation, all proposals will undergo a compliance review to verify compliance with DoD and DON SBIR/STTR submission requirements. Proposals not meeting submission requirements will be REJECTED and not evaluated.

- **Proposal Cover Sheet (Volume 1).** Not evaluated. The Cover Sheet (Volume 1) will undergo a compliance review (prior to evaluation) to verify the proposer has met eligibility requirements.
- **Technical Volume (Volume 2).** The DON will evaluate and select Phase I proposals using the evaluation criteria specified in the Phase I Proposal Evaluation Criteria section of the DoD SBIR/STTR Program BAA, with technical merit being most important, followed by qualifications of key personnel and commercialization potential of equal importance. “Best value” is defined as approaches containing innovative technology solutions to the Navy’s technical challenges for meeting its mission needs as reflected in the SBIR/STTR topics. This is not a FAR Part 15 evaluation and proposals will not be compared to one another. Cost is not an evaluation criteria and will not be considered during the evaluation process. Due to limited funding, the DON reserves the right to limit the number of awards under any topic.

The Technical Volume (Volume 2) will undergo a compliance review (prior to evaluation) to verify the proposer has met the following requirements or it will be REJECTED:

- Not to exceed 10 pages, regardless of page content
 - Single column format, single-spaced typed lines
 - Standard 8 ½” x 11” paper
 - Page margins one inch on all sides. A header and footer may be included in the one-inch margin.
 - No font size smaller than 10-point, except as permitted in the instructions above.
 - Include, within the 10-page limit of Volume 2, an Option that furthers the effort in preparation for Phase II and will bridge the funding gap between the end of Phase I and the start of Phase II. Tasks for both the Phase I Base and the Phase I Option must be clearly identified.
 - Phase I Base Period of Performance must be exactly six (6) months.
 - Phase I Option Period of Performance must be exactly six (6) months.
- **Cost Volume (Volume 3).** Not evaluated. The Cost Volume (Volume 3) will undergo a compliance review (prior to the proposal evaluation) to verify the proposer has complied with not to exceed values for the Base (\$140,000) and Option (\$100,000). Proposals exceeding either the Base or Option not to exceed values will be REJECTED without further consideration.
 - **Company Commercialization Report (Volume 4).** Not evaluated.
 - **Supporting Documents (Volume 5).** Not evaluated. Supporting Documents (Volume 5) will undergo a compliance review to ensure the proposer has included items in accordance with the PHASE I SUBMISSION INSTRUCTIONS section above.
 - **Fraud, Waste, and Abuse Training Certificate (Volume 6).** Not evaluated.

VERSION 4

ADDITIONAL SUBMISSION CONSIDERATIONS

This section details additional items for proposers to consider during proposal preparation and submission process.

Discretionary Technical and Business Assistance (TABA). The SBIR and STTR Policy Directive section 9(b) allows the DON to provide TABA (formerly referred to as DTA) to its awardees. The purpose of TABA is to assist awardees in making better technical decisions on SBIR/STTR projects; solving technical problems that arise during SBIR/STTR projects; minimizing technical risks associated with SBIR/STTR projects; and commercializing the SBIR/STTR product or process, including intellectual property protections. Firms may request, in their Phase I Cost Volume (Volume 3) and Phase II Cost Volume, to contract these services themselves through one or more TABA providers in an amount not to exceed the values specified below. The Phase I TABA amount is up to \$6,500 and is in addition to the award amount. The Phase II TABA amount is up to \$25,000 per award. The TABA amount, of up to \$25,000, is to be included as part of the award amount and is limited by the established award values for Phase II by the SYSCOM (i.e. within the \$1,700,000 or lower limit specified by the SYSCOM). As with Phase I, the amount proposed for TABA cannot include any profit/fee by the proposer and must be inclusive of all applicable indirect costs. A Phase II project may receive up to an additional \$25,000 for TABA as part of one additional (sequential) Phase II award under the project for a total TABA award of up to \$50,000 per project. A TABA Report, detailing the results and benefits of the service received, will be required annually by October 30.

Request for TABA funding will be reviewed by the DON SBIR/STTR Program Office.

If the TABA request does not include the following items the TABA request will be denied.

- TABA provider(s) (firm name)
- TABA provider(s) point of contact, email address, and phone number
- An explanation of why the TABA provider(s) is uniquely qualified to provide the service
- Tasks the TABA provider(s) will perform
- Total TABA provider(s) cost, number of hours, and labor rates (average/blended rate is acceptable)

TABA must NOT:

- Be subject to any profit or fee by the STTR proposer
- Propose a TABA provider that is the STTR proposer
- Propose a TABA provider that is an affiliate of the STTR proposer
- Propose a TABA provider that is an investor of the STTR proposer
- Propose a TABA provider that is a subcontractor or consultant of the requesting firm otherwise required as part of the paid portion of the research effort (e.g., research partner, consultant, tester, or administrative service provider)

TABA requests must be included in the proposal as follows:

- Phase I:
 - Online DoD Cost Volume (Volume 3) – the value of the TABA request.
 - Supporting Documents Volume (Volume 5) – a detailed request for TABA (as specified above) specifically identified as “Discretionary Technical and Business Assistance” in the section titled Additional Cost Information.
- Phase II:
 - DON Phase II Cost Volume (provided by the DON SYSCOM) - the value of the TABA request.

VERSION 4

- Supporting Documents (Volume 5) – a detailed request for TABA (as specified above) specifically identified as “Discretionary Technical and Business Assistance” in the section titled Additional Cost Information.

Proposed values for TABA must NOT exceed:

- Phase I: A total of \$6,500
- Phase II: A total of \$25,000 per award, not to exceed \$50,000 per Phase II project

If a proposer requests and is awarded TABA in a Phase II contract, the proposer will be eliminated from participating in the DON SBIR/STTR Transition Program (STP), the DON Forum for SBIR/STTR Transition (FST), and any other Phase II assistance the DON provides directly to awardees.

All Phase II awardees not receiving funds for TABA in their awards must attend a one-day DON STP meeting during the first or second year of the Phase II contract. This meeting is typically held in the spring/summer in the Washington, D.C. area. STP information can be obtained at: <https://navystp.com>. Phase II awardees will be contacted separately regarding this program. It is recommended that Phase II cost estimates include travel to Washington, D.C. for this event.

Disclosure of Information (DFARS 252.204-7000). In order to eliminate the requirements for prior approval of public disclosure of information (in accordance with DFARS 252.204-7000) under this award, the proposer shall identify and describe all fundamental research to be performed under its proposal, including subcontracted work, with sufficient specificity to demonstrate that the work qualifies as fundamental research. Fundamental research means basic and applied research in science and engineering, the results of which ordinarily are published and shared broadly within the scientific community, as distinguished from proprietary research and from industrial development, design, production, and product utilization, the results of which ordinarily are restricted for proprietary or national security reasons (defined by National Security Decision Directive 189). A firm whose proposed work will include fundamental research and requests to eliminate the requirement for prior approval of public disclosure of information must complete the DON Fundamental Research Disclosure and upload as a separate PDF file to the Supporting Documents (Volume 5) in DSIP as part of their proposal submission. The DON Fundamental Research Disclosure is available on https://navysbir.com/links_forms.htm and includes instructions on how to complete and upload the completed Disclosure. Simply identifying fundamental research in the Disclosure does **NOT** constitute acceptance of the exclusion. All exclusions will be reviewed and, if approved by the government Contracting Officer, noted in the contract.

Partnering Research Institutions. The Naval Academy, the Naval Postgraduate School, and other military academies are Government organizations but qualify as partnering research institutions. However, DON laboratories DO NOT qualify as research partners. DON laboratories may be proposed only IN ADDITION TO the partnering research institution.

System for Award Management (SAM). It is strongly encouraged that proposers register in SAM, <https://sam.gov>, by the Close date of this BAA, or verify their registrations are still active and will not expire within 60 days of BAA Close. Additionally, proposers should confirm that they are registered to receive contracts (not just grants) and the address in SAM matches the address on the proposal.

Notice of NIST SP 800-171 Assessment Database Requirement. The purpose of the National Institute of Standards and Technology (NIST) Special Publication (SP) 800-171 is to protect Controlled Unclassified Information (CUI) in Nonfederal Systems and Organizations. As prescribed by DFARS 252.204-7019, in order to be considered for award, a firm is required to implement NIST SP 800-171 and shall have a current assessment uploaded to the Supplier Performance Risk System (SPRS) which provides storage and retrieval capabilities for this assessment. The platform Procurement Integrated Enterprise Environment (PIEE) will

VERSION 4

be used for secure login and verification to access SPRS. For brief instructions on NIST SP 800-171 assessment, SPRS, and PIEE please visit <https://www.sprs.csd.disa.mil/nistsp.htm>. For in-depth tutorials on these items please visit <https://www.sprs.csd.disa.mil/webtrain.htm>.

Human Subjects, Animal Testing, and Recombinant DNA. Due to the short timeframe associated with Phase I of the SBIR/STTR process, the DON does not recommend the submission of Phase I proposals that require the use of Human Subjects, Animal Testing, or Recombinant DNA. For example, the ability to obtain Institutional Review Board (IRB) approval for proposals that involve human subjects can take 6-12 months, and that lengthy process can be at odds with the Phase I goal for time-to-award. Before the DON makes any award that involves an IRB or similar approval requirement, the proposer must demonstrate compliance with relevant regulatory approval requirements that pertain to proposals involving human, animal, or recombinant DNA protocols. It will not impact the DON's evaluation, but requiring IRB approval may delay the start time of the Phase I award and if approvals are not obtained within two months of notification of selection, the decision to award may be terminated. If the use of human, animal, and recombinant DNA is included under a Phase I or Phase II proposal, please carefully review the requirements at: <https://www.onr.navy.mil/work-with-us/how-to-apply/compliance-protections/Research-Protections/Human-Subject-Research.aspx>. This webpage provides guidance and lists approvals that may be required before contract/work can begin.

Government Furnished Equipment (GFE). Due to the typical lengthy time for approval to obtain GFE, it is recommended that GFE is not proposed as part of the Phase I proposal. If GFE is proposed, and it is determined during the proposal evaluation process to be unavailable, proposed GFE may be considered a weakness in the technical merit of the proposal.

International Traffic in Arms Regulation (ITAR). For topics indicating ITAR restrictions or the potential for classified work, limitations are generally placed on disclosure of information involving topics of a classified nature or those involving export control restrictions, which may curtail or preclude the involvement of universities and certain non-profit institutions beyond the basic research level. Small businesses must structure their proposals to clearly identify the work that will be performed that is of a basic research nature and how it can be segregated from work that falls under the classification and export control restrictions. As a result, information must also be provided on how efforts can be performed in later phases if the university/research institution is the source of critical knowledge, effort, or infrastructure (facilities and equipment).

SELECTION, AWARD, AND POST-AWARD INFORMATION

Notifications. Email notifications for proposal receipt (approximately one week after the Phase I BAA Close) and selection are sent based on the information received on the proposal Cover Sheet (Volume 1). Consequently, the e-mail address on the proposal Cover Sheet must be correct.

Debriefs. Requests for a debrief must be made within 15 calendar days of select/non-select notification via email as specified in the select/non-select notification. Please note debriefs are typically provided in writing via email to the Corporate Official identified in the firm proposal within 60 days of receipt of the request. Requests for oral debriefs may not be accommodated. If contact information for the Corporate Official has changed since proposal submission, a notice of the change on company letterhead signed by the Corporate Official must accompany the debrief request.

Protests. Protests of Phase I and II selections and awards must be directed to the cognizant Contracting Officer for the DON Topic Number, or filed with the Government Accountability Office (GAO). Contact information for Contracting Officers may be obtained from the DON SYSCOM Program Managers listed

VERSION 4

in Table 2. If the protest is to be filed with the GAO, please refer to instructions provided in the Proposal Fundamentals section of the DoD SBIR/STTR Program BAA.

Protests to this BAA and proposal submission must be directed to the DoD SBIR/STTR Program BAA Contracting Officer, or filed with the GAO. Contact information for the DoD SBIR/STTR Program BAA Contracting Officer can be found in the Proposal Fundamentals section of the DoD SBIR/STTR Program BAA.

Awards. Due to limited funding, the DON reserves the right to limit the number of awards under any topic. Any notification received from the DON that indicates the proposal has been selected does not ultimately guarantee an award will be made. This notification indicates that the proposal has been selected in accordance with the evaluation criteria and has been sent to the Contracting Officer to conduct cost analysis, confirm eligibility of proposer, and to take other relevant steps necessary prior to making an award.

Contract Types. The DON typically awards a Firm Fixed Price (FFP) contract or a small purchase agreement for Phase I. In addition to the negotiated contract award types listed in the section of the DoD SBIR/STTR Program BAA titled Proposal Fundamentals, for Phase II awards the DON may (under appropriate circumstances) propose the use of an Other Transaction Agreement (OTA) as specified in 10 U.S.C. 2371/10 U.S.C. 2371b and related implementing policies and regulations. The DON may choose to use a Basic Ordering Agreement (BOA) for Phase I and Phase II awards.

Funding Limitations. In accordance with the SBIR and STTR Policy Directive section 4(b)(5), there is a limit of one sequential Phase II award per firm per topic. Additionally, to adjust for inflation DON has raised Phase I and Phase II award amounts. The maximum Phase I proposal/award amount including all options (less TABA) is \$240,000. The Phase I Base amount must not exceed \$140,000 and the Phase I Option amount must not exceed \$100,000. The maximum Phase II proposal/award amount including all options (including TABA) is \$1,700,000 (unless non-SBIR/STTR funding is being added). Individual SYSCOMs may award amounts, including Base and all Options, of less than \$1,700,000 based on available funding. The structure of the Phase II proposal/award, including maximum amounts as well as breakdown between Base and Option amounts will be provided to all Phase I awardees either in their Phase I award or a minimum of 30 days prior to the due date for submission of their Initial Phase II proposal.

Contract Deliverables. Contract deliverables for Phase I are typically a kick-off brief, progress reports, and a final report. Required contract deliverables (as stated in the contract) must be uploaded to <https://www.navysbirprogram.com/navydeliverables/>.

Payments. The DON makes three payments from the start of the Phase I Base period, and from the start of the Phase I Option period, if exercised. Payment amounts represent a set percentage of the Base or Option value as follows:

Days From Start of Base Award or Option	Payment Amount
15 Days	50% of Total Base or Option
90 Days	35% of Total Base or Option
180 Days	15% of Total Base or Option

Transfer Between SBIR and STTR Programs. Section 4(b)(1)(i) of the SBIR and STTR Policy Directive provides that, at the agency's discretion, projects awarded a Phase I under a BAA for SBIR may transition in Phase II to STTR and vice versa.

VERSION 4

PHASE II GUIDELINES

Evaluation and Selection. All Phase I awardees may submit an **Initial** Phase II proposal for evaluation and selection. The evaluation criteria for Phase II is the same as Phase I. The Phase I Final Report, Initial Phase II Proposal, and Transition Outbrief (as applicable) will be used to evaluate the proposer's potential to progress to a workable prototype in Phase II and transition technology to Phase III. Details on the due date, content, and submission requirements of the Initial Phase II Proposal will be provided by the awarding SYSCOM either in the Phase I contract or by subsequent notification.

NOTE: All SBIR/STTR Phase II awards made on topics from BAAs prior to FY13 will be conducted in accordance with the procedures specified in those BAAs (for all DON topics, this means by invitation only).

Awards. The DON typically awards a Cost Plus Fixed Fee contract for Phase II; but, may consider other types of agreement vehicles. Phase II awards can be structured in a way that allows for increased funding levels based on the project's transition potential. To accelerate the transition of SBIR/STTR-funded technologies to Phase III, especially those that lead to Programs of Record and fielded systems, the Commercialization Readiness Program was authorized and created as part of section 5122 of the National Defense Authorization Act of Fiscal Year 2012. The statute set-aside is 1% of the available SBIR/STTR funding to be used for administrative support to accelerate transition of SBIR/STTR-developed technologies and provide non-financial resources for the firms (e.g., the DON STP).

PHASE III GUIDELINES

A Phase III SBIR/STTR award is any work that derives from, extends, or completes effort(s) performed under prior SBIR/STTR funding agreements, but is funded by sources other than the SBIR/STTR programs. This covers any contract, grant, or agreement issued as a follow-on Phase III award or any contract, grant, or agreement award issued as a result of a competitive process where the awardee was an SBIR/STTR firm that developed the technology as a result of a Phase I or Phase II award. The DON will give Phase III status to any award that falls within the above-mentioned description. Consequently, DON will assign SBIR/STTR Data Rights to any noncommercial technical data and noncommercial computer software delivered in Phase III that were developed under SBIR/STTR Phase I/II effort(s). Government prime contractors and their subcontractors must follow the same guidelines as above and ensure that companies operating on behalf of the DON protect the rights of the SBIR/STTR firm.

VERSION 4

Navy STTR 22.A Phase I Topic Index

N22A-T001	Visual Display Design for Mitigation of Helicopter and Tiltrotor Brownout Spatial Disorientation
N22A-T002	Multifunctional Heat Exchanger for Aerodynamic Aircraft Inlets
N22A-T003	Novel Multiphysics Modeling of Electroplating Process for Metallic Aerospace Components
N22A-T004	Automatic Hexahedral Mesh Generator for the Electromagnetic Modeling of Complex Navy Platforms with Array Antennas and Radomes
N22A-T005	Spatial Disorientation Assessment and Evaluation Tool
N22A-T006	Modeling Platform Level Electromagnetic Compatibility Performance Based on Component Level Testing
N22A-T007	Heteroepitaxy of Indium Phosphide-Based Quantum Cascade Lasers on Silicon Substrates
N22A-T008	Smart Image Recognition Sensor with Ultralow System Latency and Power Consumption
N22A-T009	DIGITAL ENGINEERING - Sonar Dome Anti-Fouling Tracking and Prediction Tool
N22A-T010	Kilowatt Class-k Fiber Optical Isolator for Submarine High Energy Laser Amplifier
N22A-T011	Shipboard Creepage and Clearance Analysis
N22A-T012	Survivable Minefield Mission Data Module
N22A-T013	Damage-Free High Power Emission from Indium Phosphide-Based Solid State Waveguides in the Long Wave Infrared
N22A-T014	Visible to Near Infrared Laser Array with Integral Wavelength Beam Combining
N22A-T015	Additive Manufacturing of High Performance Copper-Based Components and Materials
N22A-T016	DIGITAL ENGINEERING - Data-Driven Hypersonic Turbulence Modeling Toolset
N22A-T017	DIGITAL ENGINEERING - Rapid Personal Protective Equipment (PPE) Design Exploration
N22A-T018	Enhanced Sensory Perception via Advanced Synthetic Skins

VERSION 4

N22A-T019	Enhanced Thermal, Mechanical, and Physical Properties of Ceramic Matrix Composites Through Novel Additives
N22A-T020	Lidar-like 3D Imaging System for Accurate Scene Understanding
N22A-T021	Affordable Stabilized Directional Antennas for Small Platforms
N22A-T022	High Resolution Underwater Optical Ranging
N22A-T023	Aquatic Soft Robotic STEM Education Kit
N22A-T024	Marine Atmospheric Boundary Layer Profiles via Satellite-based Remote Sensing Data Fusion
N22A-T025	Enhanced Long-Range Maritime Vessel Classification
N22A-T026	Low-Cost, Low-Power Vibration Monitoring and Novelty Detection

VERSION 4

N22A-T001 TITLE: Visual Display Design for Mitigation of Helicopter and Tiltrotor Brownout Spatial Disorientation

OUSD (R&E) MODERNIZATION PRIORITY: General Warfighting Requirements (GWR)

TECHNOLOGY AREA(S): Air Platforms;Human Systems

OBJECTIVE: Design, build, and demonstrate a vertical lift platform (i.e., helicopter or tiltrotor) cockpit visual display that mitigates spatial disorientation during brownout landings and takeoffs. The display must be compatible with DoD vertical lift/aircrew systems currently in use.

DESCRIPTION: The term “brownout” refers to degradation of out-the-window cockpit visibility during landings or takeoffs from areas with loose, dry, ground soil. During brownouts, loss of visibility occurs when a helicopter or tiltrotor’s main rotor blades stir up dirt, dust, or sand, which is then re-circulated through the blades and over the windscreen during low ground hover operations. The Joint Air Power Competence Centre (JAPCC) reported that the most dangerous action a helicopter pilot can take is land in brownout conditions. Additionally, it cited a USAF Institute of Technology report which states that the U.S. Department of Defense (DoD) had over 100 million USD in costs attributed to brownout mishaps. Furthermore, 65% of non-hostile fatalities have been from brownout hover and low speed flight. A final conclusion from the JAPCC’s report was that while many phases of helicopter flight can be performed with only instrument scanning, landing and hovering cannot [Ref 1].

During vertical hover landings or takeoffs with good outside visibility, rotary-wing and tiltrotor pilots maintain spatial orientation by using two types of outside visual cues. The first is a distant view of a horizontal reference that can be used for detecting unintended roll or pitch motions, and the second is a view of nearby fixed ground objects used as references for detecting unintended yaw, side drift, or forward and aft motion. With Visual Meteorological Conditions (VMC), primary spatial cues for rotary-wing and tiltrotor pilots are defined as fixed foveal views of distant (horizon) or near (ground) references. In contrast, secondary spatial cues have been defined as unstabilized peripherally viewed objects (such as cockpit components or outside airframe structures) that are perceived as being in motion as they change retinal position relative to the stabilized primary cue. Together, fixed primary and moving secondary spatial cues create a dynamic sight picture that allows pilots to use a VMC spatial strategy for determining aircraft attitude and directional rate of movement [Ref 2]. If visibility of either primary cue type is blocked by circulating particles within the rotor blade vortex ring, the pilot will suffer an immediate loss of critical spatial information, which unfortunately, also creates a high potential for spatial disorientation (SD) and incorrect control inputs.

When brownouts cause pilots to suddenly lose their outside visual cues seconds before touchdown, they are forced instantly to decide whether to attempt a rapid instrument transition or continue with an outside scan, hoping to see a visual ground reference seconds before setting down. Unfortunately, when transitioning from an outside view to head down instruments, the Federal Aviation Administration (FAA) has documented that establishing full instrument control after the loss of surface visual reference can take as much as 35 seconds [Ref 3]. With brownout conditions, sudden loss of the primary spatial cues (horizon and ground) and the limited time available to successfully transition to instruments, creates a high risk for SD.

Researchers have demonstrated that pilots exhibit specific reflexive head and eye movements that influence sight picture dynamics in a manner that aids with development of VMC spatial strategies [Refs 2, 4, and 5]. Brownout visual countermeasures that accommodate these normal pilot behaviors may help reduce pilot spatial problems known to occur with less than optimum display designs. To mitigate this

VERSION 4

risk, the DoD is seeking a non-energy signature emitting visual display system with a presentation that will mimic pilot outside spatial strategies when encountering degraded visual environments (DVE).

Proposed display designs should enable a seamless transition time between real-world spatial cues and display symbology and consideration should be given for incorporation of flight path predictor type symbology. Design proposals should also describe, in general terms, compatibility with existing rotary-wing and tiltrotor systems such as (but not limited to): weight issues, cost estimate assessment, display transition time, and usability with both day and night conditions.

The prototype display should be constructed in a manner compatible with both stationary (non-motion) flight simulator and a motion-based flight simulator with six degrees of freedom (6DOF). The first stage of the evaluation should involve non-motion flight simulation with brownout conditions and the second stage should repeat stage one in a simulated flight environment with full 6DOF motion. Since the combined motion and visual environments of rotary-wing and tiltrotor brownout usually involve 6DOF, the Navy Disorientation Research Device (DRD) at the Naval Medical Research Unit Dayton, Wright-Patterson Air Force Base, Ohio, may be considered as a potential test facility for Phases II and III efforts. It is expected that a fully operational and complete (hardware and software) brownout mitigation visual display prototype will not require input from airframe emitted sensory energy and will operate using open-source software that is compatible with desktop Microsoft CPU systems. Device prototype and test subject raw performance data collected in ASCII format during test and evaluation with motion and non-motion based brownout simulations. Phase II final report that contains a detailed schematic and a complete description for operation of the brownout mitigation visual display system. The final report should also include a detailed analysis of the performance testing data collected during motion and non-motion brownout simulations.

Test and evaluation should demonstrate the prototype display capability for preventing SD during sudden and unexpected encounters with brownout conditions during high workload conditions. The experimental design for evaluating the working prototype should include DoD rotary-wing and tiltrotor pilots as test subjects and have a statistical power of 0.80 or higher. Dependent variables for display assessment should include, but not be limited to, pilot landing and takeoff tracking performance (roll, pitch, yaw, ascent, descent, airspeed, and drift), Opto-Kinetic Cervical Reflex (OKCR) response, eye tracking, Control Reversal Errors (CRE), subjective workload assessment, and motion sickness susceptibility.

Note: NAVAIR will provide Phase I performers with the appropriate guidance required for human research protocols so that they have the information to use while preparing their Initial Phase II Proposal. Institutional Review Board (IRB) determination as well as processing, submission, and review of all paperwork required for human subject use can be a lengthy process. As such, no human research will be allowed until Phase II and work will not be authorized until approval has been obtained, typically as an option to be exercised during Phase II.

PHASE I: Develop, describe, and define potential methodologies and designs for a visual display system that will prevent loss of spatial awareness during DVE encountered with brownout conditions. During the Phase I process, plans for designing an optimum visual countermeasure for brownout should take into consideration the types of cognitive processing pilots use with inflight spatial strategies, during both VMC and Instrument Meteorological Conditions (IMC). Provide detailed Phase I final report that includes concepts and plans to develop and test a brownout mitigation visual display for rotary-wing aircraft in stationary and 6DOF simulators. The Phase I effort will include prototype plans to be developed under Phase II.

Note: Please refer to the statement included in the Description above regarding human research protocol for Phase II.

VERSION 4

PHASE II: Develop a working prototype visual display for mitigating or eliminating pilot SD during brownout takeoffs and landings.

Note: Please refer to the statement included in the Description above regarding human research protocol for Phase II.

PHASE III DUAL USE APPLICATIONS: Integrate display design into a 6DOF motion simulator and vertical lift platform. Final end user testing, validation, and verification of the display system in DVE conditions.

Private sector or corporate transportation services that utilize vertical lift platforms (i.e., helicopters) can experience degraded visual environments due to unexpected weather conditions or terrain challenges. These conditions can lead to mishaps due to resulting spatial disorientation. In addition, federal (e.g., USCG, DHS, FBI), state (National Guard units, Civil Air Patrol), or local (e.g., Firefighter/Paramedics, life flight) government search and rescue that utilize vertical lift platforms may benefit from the use of an advanced display design to mitigate spatial disorientation associated with DVE conditions. A secondary application may be in the display system used with unmanned aerial systems with vertical lift capabilities.

REFERENCES:

1. Modesto, M. (2017). "Beating brownout: Technology helps, but training remains key." Joint Air Power Competence Centre. <https://www.japcc.org/ beating-brownout/>.
2. Patterson, F. R., Cacioppo, A. J., Gallimore, J. J., Hinman, G. E., & Nalepka, J. P. (1997). "Aviation spatial orientation in relationship to head position and attitude interpretation." *Aviation, Space, and Environmental Medicine*, 68(6), 463–471. https://www.researchgate.net/publication/14033635_Aviation_spatial_orientation_in_relationship_to_head_position_and_attitude_interpretation.
3. Hunt, K. S. (1983, February 9). "Advisory circular: Pilot's spatial disorientation." AC No. 60-4A. Federal Aviation Administration. https://www.faa.gov/documentLibrary/media/Advisory_Circular/AC60-4A.pdf.
4. Patterson, F. R., & Muth, E. R. (2010, September 9). "Cybersickness onset with reflexive head movements during land and shipboard head-mounted display flight simulation, Report Number 10-43." Naval Aerospace Medical Research Laboratory. <https://apps.dtic.mil/sti/pdfs/ADA528015.pdf>.
5. Moore, S. T., MacDougall, H. G., Lesceu, X., Speyer, J. J., Wuyts, F., & Clark, J. B. (2008). "Head-eye coordination during simulated orbiter landing." *Aviation, Space, and Environmental Medicine*, 79(9), 888-898. <https://doi.org/10.3357/ASEM.2209.2008>.
6. Naval Medical Research Unit Dayton. (n.d.). "Disorientation research device: The Kraken(TM)." Retrieved March 24, 2021, from <https://www.med.navy.mil/sites/nmrc/NAMRUDayton/Directorates/Admin/Pages/Disorientation-Research-Device.aspx>.

KEYWORDS: Degraded visual environment; DVE; future vertical lift; spatial disorientation; display symbology; display design; human factors

VERSION 4

N22A-T002 TITLE: Multifunctional Heat Exchanger for Aerodynamic Aircraft Inlets

OUSD (R&E) MODERNIZATION PRIORITY: Directed Energy (DE);General Warfighting Requirements (GWR)

TECHNOLOGY AREA(S): Air Platforms

OBJECTIVE: Develop an aerodynamic, multifunctional heat exchanger that is capable of dissipating a large amount of aircraft waste heat while improving inlet flow distortion upstream of a gas turbine engine.

DESCRIPTION: Inlet guide vanes offer a potentially attractive way to remove heat from aircraft and engine coolants. Doing so, however, adds complexity and volume to conventional guide vanes, which are also ill-suited for convoluted inlets with complex aerodynamics. The volume added to conventional guide vanes results in aerodynamic losses and weight penalties that can negate the gains from multifunctionality. More elegant, combined aerodynamic/heat exchanger solutions may be feasible given the current state-of-the-art in multi-objective optimization, additive manufacturing, and custom flow tailoring. Advanced diffuser designs often involve flow separation and large-scale unsteady flow features which reduce the diffuser efficiency and subject the downstream turbomachinery to extreme flow distortions. Solutions are sought for a new heat exchanger technology that can simultaneously improve inlet diffuser aerodynamic performance. The heat transfer and aerodynamic flow field characteristics of the proposed technology need to be fully understood to ensure gas turbine engine compatibility and enable future, advanced Navy propulsion systems.

The proposed solutions will be required to demonstrate the following criteria:

- Heat exchanger effectiveness greater than, or equal to, 0.4.
- A total pressure drop across the heat exchanger no greater than 8%.
- A decrease in the element average circumferential and radial distortions as defined in SAE AIR 1419C [Ref 5].
- The front face of the heat exchanger positioned no more than two (2) diameters upstream of the Aerodynamic Interface Plane (AIP).

Though not required criteria, proposed solutions are encouraged to consider impacts and capabilities on the air platform as a whole. Metrics such as weight, serviceability, propulsion performance, and working fluid are important aspects to overall feasibility and utility. Values are not imposed so that the design space is not overly constrained. It is advised that total system estimated weight (including installation and plumbing) not to exceed 50lbm, and must fit within an existing inlet geometry (Ref 3 may be used for a defined geometry).

It is recommended to collaborate with an original equipment manufacturer (OEM) for Phase II studies, and Phase III integrated testing to identify representative installation configurations and performance needs.

PHASE I: Demonstrate feasibility of the proposed technology through computational and system-level analysis of a proposed concept, and in a simplified flow environment at the bench level. Detailed benefits of this concept, relative to existing technologies, should be identified. The Phase I effort will include prototype plans to be developed under Phase II.

PHASE II: A prototype device should be designed, built, and tested to evaluate heat exchanger effectiveness, pressure loss, and distortion reduction in a representatively complex inlet (serpentine, varying cross-sectional area and shape; Ref 3).

VERSION 4

PHASE III DUAL USE APPLICATIONS: Integrated test should be performed to evaluate the impact the multifunctional heat exchanger has on power plant performance. Transition the technology to applicable naval platform or lab.

Heat dissipation and flow straightening are not military specific concerns. Commercial aircraft/rotorcraft could also take advantage of this topic. Improvements to air flow into engines provide great operational safety and reliance for air vehicles.

Commercialization of this technology may include industrial applications for flow conditioning and heat exchangers, as well as advanced concepts for commercial transport aircraft and automotive applications.

This technology could also be applied for regenerative engine cycles. The ability to utilize the waste exhaust thermal energy of a power cycle to heat incoming air can provide an increase in cycle efficiency and decrease in fuel consumption. Additive manufacturing could provide the opportunity to retrofit existing systems to take advantage of regeneration.

REFERENCES:

1. Guimarães, T., Lowe, K. T., & O'Brien, W. F. (2017, October 31). "StreamVane turbofan inlet swirl distortion generator: Mean flow and turbulence structure." *AIAA Journal of Propulsion and Power*, 34(2), 340-353. <https://doi.org/10.2514/1.B36422>.
2. Nessler, C. A., Copenhaver, W. W., & List, M. G. (2013, January 7-10). "Serpentine diffuser performance with emphasis on future introduction to a transonic fan [Paper presentation]." In 51st AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition, Grapevine (Dallas/Ft. Worth Region), TX, United States. <https://doi.org/10.2514/6.2013-219>.
3. Maghsoudi, I., Mahmoodi, M., & Vaziri, M. A. (2020, January 28). "Numerical design and optimization of mechanical vane-type vortex generators in a serpentine air inlet duct." *European Physical Journal Plus*, 135(2), 139. <https://doi.org/10.1140/epjp/s13360-020-00124-1>.
4. Reichert, B. A., & Wendt, B. J. (1996). "Improving curved subsonic diffuser performance with vortex generators." *AIAA Journal*, 34(1), 65-72. <https://doi.org/10.2514/3.13022>.
5. SAE International Aerospace Council Divisional Technical Committee S-16. (2017, November 20). "AIR1419C: Inlet total-pressure-distortion considerations for gas-turbine engines." SAE International, November 20, 2017. <https://www.sae.org/standards/content/air1419c/>.

KEYWORDS: Thermal management; Inlets; Heat Exchangers; Propulsion Performance; Inlet Distortion; Additive Manufacturing

VERSION 4

N22A-T003 TITLE: Novel Multiphysics Modeling of Electroplating Process for Metallic Aerospace Components

OUSD (R&E) MODERNIZATION PRIORITY: Artificial Intelligence (AI)/Machine Learning (ML)

TECHNOLOGY AREA(S): Air Platforms;Materials / Processes

OBJECTIVE: Develop a coupled electro-chemo-mechanical model to optimize electroplating parameters, and to predict the influence of surface roughness, porosities/defects, and residual stresses due to zinc-nickel (Zn-Ni) coating on fatigue strength of high strength steel (HSS) aerospace components.

DESCRIPTION: Naval aircraft operate routinely in a very severe saltwater environment, and corrosion damage is the leading cause affecting fleet readiness and total life cycle cost. The Navy spends about \$3.7 billion a year on corrosion maintenance and repairs. Corrosion fatigue can also lead to catastrophic failures of aircraft primary structures. Electrodeposition of cadmium coating on high strength steel (HSS) components has been very effective in providing protection against corrosion. However, cadmium—a known carcinogen—creates environmental hazards, and occupational safety and health (OSH) risks. Recently, a new alkaline Zn-Ni coating process has been developed and shown promises as a suitable replacement for cadmium plating.

HSS alloys such as 300M and 4340 are susceptible to hydrogen embrittlement. During the electroplating process, the released hydrogen gas could be absorbed into the substrate, which can cause the loss of ductility, static, and fatigue strength of the base metal. Furthermore, hydrogen can also be absorbed into the HSS components when the coating corrodes in service. This hydrogen re-embrittlement (H-RE) mechanism could also lead to premature structural failures.

In addition, surface roughness, coating thickness/uniformity, porosities/microcracking, residual stresses, and pre- and post-treatment can have a significant impact on not only the effectiveness and durability of the coating system, but also on the components' fatigue performance. Electrolyte chemical composition, current density, part geometries, and anode-cathode placement/spacing and surface areas are also contributors to the plating variations.

Current process characterization, optimization, and qualification are predominantly empirical based requiring extensive testing, a costly and very time-consuming effort. This must be repeated for each of the HSS alloys.

The Navy requires an integrated suite of software tools that accelerate the optimization and qualification process, and quickly assess the impacts of electroplating on the structural integrity, including material properties and fatigue performance of HSS aircraft components (e.g., landing gears) subjected to naval operating environments. The modeling approach should consider the interplay between residual stresses, porosities/defects, and microstructure evolution on fatigue strength of the metallic materials. The proposed research should also provide a two-way coupling between the corrosion damage and mechanical stresses (internal/residual and externally applied) for capturing the synergistic effects of mechanical loading and corrosion on the integrity of the electroplated parts.

The specific aims are: (a) modeling residual stress generation during electrodeposition, (b) predicting fatigue strength of the base metal considering surface roughness, porosities/defects, and residual stresses, and (c) developing multiobjective optimization algorithm for the plating process.

PHASE I: Develop a modeling concept and computational framework for electrodeposition and optimization of Zn-Ni coating on a HSS (300M or 4340) structural component (e.g., landing gears). Demonstrate feasibility of the proposed concept to predict residual stresses, coating thicknesses, and

VERSION 4

fatigue performance of the electroplated part under constant and variable amplitude spectra. Develop a qualification testing plan for the optimized coating. The Phase I effort will include prototype plans to be developed under Phase II.

PHASE II: Develop multiobjective optimization algorithm for electroplating process. Develop and demonstrate a beta software tool for electroplating Zn-Ni coating on HSS (300M or 4340) parts. Validate the model predictions with experimental test coupons and representative structural parts subjected to constant and variable amplitude spectra. Perform qualification testing for the optimized coating in accordance with the test plan developed in Phase I. Demonstrate by testing that the corrosion protection and fatigue performance of the optimized Zn-Ni plated component under constant amplitude and variable amplitude spectrum to be equivalent or better than the cadmium plated part.

PHASE III DUAL USE APPLICATIONS: Demonstrate the scalability and effectiveness of the tools for different HSS alloys such as Aermet100, 17-4PH and HYTUF. Perform qualification testing on a full-scale component to validate the software predictions. Transition the tools to U.S. Government depots and commercial industries.

In addition to aerospace, the transportation industry—such as automotive—will benefit greatly from this technology for optimizing plating of transmission gears made from high strength steel alloys for better corrosion and wear resistance performance.

REFERENCES:

1. Read, H. J. (1967). "Metallurgical aspects of electrodeposits." *Plating*, 54(1), 33-42. https://www.nmfr.org/pdf/2018/07harold_read1966.pdf.
2. Weil, R. (1982). "Material science of electrodeposits." *Material Science*. <https://www.nmfr.org/pdf/stwp/2012-03-01.pdf>.
3. Raub, C. J. (1993). "Hydrogen in electrodeposits: of decisive importance, but much neglected." *Plating and Surface Finishing*, 80(9), 30-38. https://www.nmfr.org/pdf/2018/34christoph_raub1993.pdf.
4. Gabe, D. R. (1997). "The role of hydrogen in metal electrodeposition processes." *Journal of Applied Electrochemistry*, 27(8), 908-915. <https://doi.org/10.1023/A:1018497401365>.
5. Stein, M., Owens, S. P., Pickering, H. W., & Weil, K. G. (1998). "Dealloying studies with electrodeposited zinc-nickel alloy films." *Electrochimica acta*, 43(1-2), 223-226. [https://doi.org/10.1016/S0013-4686\(97\)00228-4](https://doi.org/10.1016/S0013-4686(97)00228-4).
6. Weil, R. (1994). "Aspects of the mechanical properties of electrodeposits." *MRS Online Proceedings Library (OPL)*, 356. <https://doi.org/10.1557/PROC-356-119>
7. Hearne, S. J. (2008). "Origins of Stress During Electrodeposition (No. SAND2008-2533C)." Sandia National Lab.(SNL-NM), Albuquerque, NM (United States). <https://www.osti.gov/servlets/purl/1145482>.
8. Crotty, D., Lash, R., & English, J. (1999). "Performance of zinc-nickel alloy electrodeposits as affected by internal stress." *SAE transactions*, 28-39. <https://www.jstor.org/stable/44650584>.
9. Felder, E. C., Nakahara, S., & Well, R. (1981). "Effect of substrate surface conditions on the microstructure of nickel electrodeposits." *Thin Solid Films*, 84(2), 197-203. [https://doi.org/10.1016/0040-6090\(81\)90469-7](https://doi.org/10.1016/0040-6090(81)90469-7).
10. Voorwald, H. J. C., Rocha, P. C. F., Cioffi, M. O. H., & Costa, M. Y. P. (2007). "Residual stress influence on fatigue lifetimes of electroplated AISI 4340 high strength steel." *Fatigue & Fracture of Engineering Materials & Structures*, 30(11), 1084-1097. <https://doi.org/10.1111/j.1460-2695.2007.01178.x>.
11. Sabelkin, V., Misak, H., & Mall, S. (2016). "Fatigue behavior of Zn-Ni and Cd coated AISI 4340 steel with scribed damage in saltwater environment." *International Journal of Fatigue*, 90, 158-165. <https://doi.org/10.1016/j.ijfatigue.2016.04.027>.

VERSION 4

12. (2016). “ASTM E8/E8M-16ae1, Standard test methods for tension testing of metallic materials.” ASTM International. <https://www.astm.org/DATABASE.CART/HISTORICAL/E8E8M-16AE1.htm>.
13. (2019). “ASTM E606/E606M-19e1, Standard test method for strain-controlled fatigue testing.” ASTM International. <https://www.astm.org/Standards/E606.htm>.
14. Waalkes, M. P. (2003). “Cadmium carcinogenesis.” Mutation Research/Fundamental and Molecular Mechanisms of Mutagenesis, 533(1-2), 107-120. <https://doi.org/10.1016/j.mrfmmm.2003.07.011>.
15. Fernandes, M. F., dos Santos, J. R. M., de Oliveira Velloso, V. M., & Voorwald, H. J. C. (2020). “AISI 4140 steel fatigue performance: Cd replacement by electroplated Zn-Ni Alloy Coating.” Journal of Materials Engineering and Performance, 1-12. <https://doi.org/10.1007/s11665-020-04669-1>.
16. Barrera, O. et al. (2018). “Understanding and mitigating hydrogen embrittlement of steels: a review of experimental, modelling and design progress from atomistic to continuum.” Journal of materials science, 53(9), 6251-6290. <https://doi.org/10.1007/s10853-017-1978-5>.

KEYWORDS: electroplating; zinc-nickel coating; high strength steel; fatigue strength; corrosion protection; wear resistance

VERSION 4

N22A-T004 TITLE: Automatic Hexahedral Mesh Generator for the Electromagnetic Modeling of Complex Navy Platforms with Array Antennas and Radomes

OUSD (R&E) MODERNIZATION PRIORITY: Networked C3

TECHNOLOGY AREA(S): Air Platforms

OBJECTIVE: Develop an advanced tool for automatically generating hexahedral meshes for high-fidelity simulation of electronically scanned array antennas on Navy platforms.

DESCRIPTION: Currently, many powerful fully automatic mesh generation tools are available that employ tetrahedral cells to mesh complex geometries, including full aircraft Computer-aided Design (CAD) models. These tetrahedral meshes are in general unable to provide the same level of solution accuracy as hexahedral meshes. Another important advantage of a hexahedral mesh over a tetrahedral mesh is the reduction in the number of elements for the same level of analysis accuracy. However, creating hexahedral meshes, especially for complex geometries such as full aircraft, is a tedious and time-consuming process that significantly burdens many realistic engineering analyses and design cycles.

Conducting performance analysis of very complex antennas on full aircraft configuration for Navy applications can be significantly improved by employing a hexahedral mesh. Such antennas include passive phased array (PESA), active electronically scanned array (AESA), hybrid beam forming phased array, and digital beam forming (DBF) array. These types of antennas have small-scale complex internal features that need to be precisely captured by a given mesh. At the same time, the location of these antennas on the aircraft is also important and needs to be optimized. As such, the combination of greatly varying mesh scales and the number simulations that need to be performed are significant factors that can take advantage of a hexahedral mesh that will allow for better accuracy with significantly reduced overall simulation time. The ability to produce highly accurate on-aircraft antenna responses at the element level (fractions of a dB in the main beam) while reducing run-time by adaptively meshing the model is critical. Taking advantage of the latest developments in hexahedral meshing technology [Refs 1–3] to create fully hexahedral or strongly hex-dominant (98% or more hex) meshes for applications involving installed phased array antennas on full aircraft configurations is a possible means to address this topic. The approach should provide capabilities to import CAD models (IGES, STEP, STL, etc.) and subsequent geometry cleanup and preparation for meshing. Provide capabilities to write out mesh in CGNS format for subsequent use with EM simulation tools.

PHASE I: Demonstrate the feasibility of an automatic hexahedral mesh, or a hexahedral dominant mesh generation tool, for simulation of complex phased array antennas on full aircraft platforms. Initiate development work on a user friendly Graphic User Interface (GUI) or integrate into an existing mesh generation tool to enable the user to efficiently (relative to that of existing commercial codes using tetrahedral meshing), set up a geometry model and create a hexahedral mesh capturing details of the antenna and aircraft geometry. The demonstration should compare accuracy of simulations using the hexahedral meshes with those using tetrahedral meshes for a variety of canonical electromagnetic problems.. The Phase I effort will include prototype plans to be developed under Phase II.

PHASE II: Develop a prototype hexahedral mesh generator tool. Continue work on further development and improvement of the algorithm initiated during Phase I. Complete the related GUI development work. Include performance metrics using advanced EM simulation tools to show expected performance efficiencies compared to conventional tetrahedral meshes. Show ease of use and operability utilizing realistic CAD models of installed phased array antennas on the aircraft. Provide the option of creating tetrahedral meshes as needed by the end user.

VERSION 4

PHASE III DUAL USE APPLICATIONS: Complete development, and perform final testing of a commercial grade application for use by radar, antenna, and computational electromagnetics engineers.

The approach is applicable to any electrically large complex system including commercial aircraft or automobiles.

REFERENCES:

1. Livesu, M., Pietroni, N., Puppo, E., Sheffer, A., & Cignoni, P. (2020). "LoopyCuts: practical feature-preserving block decomposition for strongly hex-dominant meshing." *ACM Transactions on Graphics (TOG)*, 39(4), 121-1. <https://doi.org/10.1145/3386569.3392472>.
2. Li, Y., Liu, Y., Xu, W., Wang, W., & Guo, B. (2012). "All-hex meshing using singularity-restricted field." *ACM Transactions on Graphics (TOG)*, 31(6), 1-11. <https://doi.org/10.1145/2366145.2366196>.
3. Liu, H., Zhang, P., Chien, E., Solomon, J., & Bommers, D. (2018). "Singularity-constrained octahedral fields for hexahedral meshing." *ACM Transactions on Graphics*, 37(4), Article No. 93, 1. <https://doi.org/10.1145/3197517.3201344>.

KEYWORDS: computational electromagnetics; Hexahedral Mesh; modeling and simulation; antennas; radome; antenna array

VERSION 4

N22A-T005 TITLE: Spatial Disorientation Assessment and Evaluation Tool

OUSD (R&E) MODERNIZATION PRIORITY: General Warfighting Requirements (GWR)

TECHNOLOGY AREA(S): Air Platforms;Human Systems

OBJECTIVE: Develop and validate a survey-based assessment tool aimed at measuring perceptions regarding the experience and severity of a spatial disorientation-related illusion, as well as to evaluate the effectiveness of knowledge/skill acquisition and attitudinal changes from spatial disorientation training protocols.

DESCRIPTION: Spatial disorientation (SD) is one of the most cited accident-causing factors in aviation and accounts for 33% of all aviation accidents [Ref 2]. This trend has increased over time due to the rise in licensed pilots and hours flown; however, little research has been done to address the measurement of knowledge, skills, and attitudes required to combat an SD incident. Rather, the majority of current and prior literature focuses on improving the technology utilized to improve SD training. While technological updates to modern SD training simulations have been shown to improve SD-related outcomes [Refs 3–6] (i.e., subjective identification of SD illusions, successful simulation, and elicitation of illusions), the lack of observational and survey scales to assess the true effect that SD training methods have on aviators is concerning. Specifically, no current or prior literature attempts to analyze and present the specific knowledge, skills, and abilities (KSA) that their study's training conditions were meant to target. This systematic lack of KSA identification during training assessment is concerning as they remain the most predictive and valid metrics of competencies that relate to an individual's abilities to perform a task [Ref 1].

Recent advances in the SD training domain have sought to mitigate this challenge by producing a set of training competencies that are believed to be associated with SD training outcomes. A recent Training Systems Requirements Analysis focused on advanced spatial disorientation was developed via a subject matter expert review of prior SD training and competency literature. Various current and prior SD training programs also informed this analysis in order to ensure that the information taught in future SD training programs, to both indoctrination and refresher aviators, will improve their knowledge of SD, their skills in employing tactics against it, and their attitudes towards utilizing training and safety procedures for SD. However, while previous analyses provide the most comprehensive list of competencies for SD training to date, the competencies and methods of measuring said competencies have not undergone documented validation. Psychometric validation is a statistically quantitative process concerned with determining if the metrics utilized to measure latent constructs (i.e., illusion identification ability) are measuring latent constructs reliably and consistently. Without the validation of questions and behavioral observations to underpin analysis results, it is unclear whether the protocols will truly target key SD avoidance, mitigation, and countermeasure competencies required by aviators. Further, it is possible that without appropriate psychometric validation, future efforts will have opposing effects on SD training by missing key components of the required KSA.

Developing a validated SD assessment and evaluation tool provides an opportunity to formulate a data-driven method to both measure SD mitigation and countermeasure knowledge and behavior, while also providing a differential measurement to assess training effectiveness resulting in validated training methods. A software-based assessment tool would assist trainers in not only developing more effective training protocols and procedures, but also personalizing SD training feedback to student aviators. The final decision support tool product will enable a standardized, reliable, and valid measurement of real-time training SD episode mitigation and reaction knowledge and skills. The hardware and software must meet the system DoD accreditation and certification requirements to support processing approvals for use through the policy cited in Department of Defense Instruction (DoDI) 8510.01, Risk Management

VERSION 4

Framework (RMF) for DoD Information Technology (IT) [Refs 7, 8], and comply with appropriate DoDI 8500.01, Cybersecurity [Refs 7, 8, 9]. Finally, research into the effectiveness of the instructional strategies and technologies developed based on these concepts is necessary to determine feasibility prior to transition.

PHASE I: Develop a psychometrically-based validation protocol to assess relevant SD competencies (e.g., application of procedures, communication, safety of flight management, automated and/or manual aircraft control, leadership, crew resource management, problem solving, decision making, situation awareness, workload management). Design the framework of the software-based tool to ensure a high level of end-user use reliability and usability. Develop the user-interaction architecture of the software tool for user input, output, and modification of the validated survey. Deploy psychometric validity testing. The Phase I effort will include prototype plans to be developed under Phase II.

PHASE II: Develop a validated questionnaire and observation tool of SD mitigation and countermeasure KSA from validity testing. Incorporate the initial questionnaire and observation tool into the software-based application for prototype demonstration and testing. Deploy confirmatory testing of validated questionnaire and observation tool. Finalize the questionnaire and observational assessment tool.

PHASE III DUAL USE APPLICATIONS: Obtain management framework certification for an authority to operate to successfully transition to a NAVAIR program office. Based on Phase II results, finalize and refine the methodology (questionnaire/observation tool) and software developed to meet training requirements for a wider variety of SD events/scenarios or platforms to support transition and commercialization of the product. Investigate the potential of expanding the software-based application to validate additional relevant training environments to extend transition applicability.

The validation framework and evaluation software has applicability to commercial industries including commercial airlines and corporate training. Demonstration of a methodologically sound software technology to validate training system needs has broader DoD and commercial applicability.

REFERENCES:

1. Bloom, B. S. (1956). "Taxonomy of educational objectives. Handbook 1: Cognitive domain." Addison-Wesley Longman Ltd; 2nd edition. https://www.amazon.com/Taxonomy-Educational-Objectives-Handbook-Cognitive/dp/0582280109/ref=sr_1_2?crd=194EH99NIT4AZ&dchild=1&keywords=taxonomy+of+educational+objectives&qid=1616611649&s=books&prefix=Taxonomy+of%2Caps%2C438&sr=1-2.
2. Gibb, R., Ercoline, B., & Scharff, L. (2011). "Spatial disorientation: decades of pilot fatalities." *Aviation, Space, and Environmental Medicine*, 82(7), 717–724. <https://doi.org/10.3357/ASEM.3048.2011>.
3. Kallus, K. W., & Tropper, K. (2004). "Evaluation of a spatial disorientation simulator training for jet pilots." *International Journal of Applied Aviation Studies*, 4(1), 4556. https://www.academy.jccbi.gov/ama-800/Spring_2004.pdf#page=45.
4. Tropper, K., Kallus, W., & Boucsein, W. (2009). "Psychophysiological evaluation of an antidisorientation training for visual flight rules pilots in a moving base simulator." *The International Journal of Aviation Psychology*, 19(3), 270–286. https://www.worldcat.org/title/psychophysiological-evaluation-of-an-antidisorientation-training-for-visual-flight-rules-pilots-in-a-moving-base-simulator/oclc/770679956&referer=brief_results.
5. Kallus, W., Tropper, K., & Boucsein, W. (2011). "The importance of motion cues in spatial disorientation training for VFR-pilots." *The International Journal of Aviation Psychology*, 21(2), 135–152. https://www.worldcat.org/title/the-importance-of-motion-cues-in-spatial-disorientation-training-for-vfr-pilots/oclc/710990109&referer=brief_results.

VERSION 4

6. Stroud, K. J., Harm, D. L., & Klaus, D. M. (2005). "Preflight virtual reality training as a countermeasure for space motion sickness and disorientation." *Aviation, Space, and Environmental Medicine*, 76(4), 352-356.
<https://www.ingentaconnect.com/content/asma/ asem/2005/00000076/00000004/art00006>
7. Department of Defense. (2014). Risk Management Framework (RMF) for DoD Information Technology (IT). Washington D.C.: Executive Services Directorate.
https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/851001_2014.pdf.
8. BAI Information Security Consulting & Training. (2020). BAI: Information Security RMF Resource Center. Retrieved from Risk Management Framework. <https://rmf.org/>.
9. Department of Defense Instruction 8510.01. <https://www.acqnotes.com/wp-content/uploads/2016/08/DoDI-8510.01-Risk-Management-Framework-for-DoD-Information-Technology-%E2%80%93-24-May-2016.pdf>.
10. FREQUENTLY ASKED QUESTIONS https://navysbir.com/n22_a/N22A-T005_FAQs.pdf

KEYWORDS: Spatial disorientation; training; validated training methods; decision support tool; psychometric validation; training competencies

VERSION 4

N22A-T006 TITLE: Modeling Platform Level Electromagnetic Compatibility Performance Based on Component Level Testing

OUSD (R&E) MODERNIZATION PRIORITY: Networked C3

TECHNOLOGY AREA(S): Air Platforms

OBJECTIVE: Develop a simulation tool that will evaluate the risk to a platform given a component that has failed to meet its electromagnetic compatibility (EMC) test requirements (e.g., MIL-STD-461; [Ref 1]).

DESCRIPTION: In order to work toward successful platform level integration, there is a long-established workflow for EMC. In this procedure, individual electronic modules are designed and tested to certain standards, usually based on MIL-STD-461 [Ref 1], which impose limits on radiated and conducted emissions and radiated and conducted susceptibility. Any unit that passes those tests is assumed to be ready for integration onto the platform for its application with the expectation that it will not interfere with neighboring equipment and will operate in its intended electromagnetic environment.

As long as this process has been in place, there were countless examples of modules that failed to pass the mandated requirements. Each time this happens the standard process step was to instruct the supplier to redesign the module until it meets the specified requirements. However, there are often counter arguments that these redesigns can add cost, weight, and potentially jeopardize schedules. Engineers are often left to evaluate the potential risk of allowing a given noncompliant module to waive certain requirements based on past experience, personal judgement, and general heuristics.

The goal of this STTR effort is to give engineers in that position a tool that will allow them to take component-level testing data and model the potential effects when that module is placed in a realistically modeled platform. This involves developing a program to read in radiated emissions or susceptibility data from a test report. It would then create a model of a source or victim by backwards propagating the test data (usually taken at 1 m separation distance). That source or victim unit would then be placed in a model of the full platform with realistic grounding, bonding, and cable routing. A simulation would then be run to determine if emissions from the offending unit had negative impacts on neighboring systems or the external environment, or to see if the exterior electromagnetic environment would be likely to cause susceptibility upsets in the unit. The end result would not be to achieve an exact simulation result to compare to future testing, but instead to give engineers an analysis to show that the units' behavior will likely be severely noncompliant, marginal, or very benign. This will allow for more accurate data-driven risk assessments in the cases of noncompliant modules seeking waivers to requirements. An objective is to identify at least 90% of severely non-compliant situations using this simulation.

PHASE I: Develop a workflow that ties together all the necessary steps for the analysis: reading in test report data; converting it to a usable format; mathematically back-propagating the source or victim that yields the emissions or susceptibility profile; assigning those properties to a module that can be placed in a CAD model of a full platform with worst-case assumptions about grounding, bonding, and cable-routing; and running a simulation to compare the unit's performance to platform level requirements. The Phase I effort will include prototype plans to be developed under Phase II.

PHASE II: Develop a prototype new user interface and computational engine for the simulation capabilities and integrate the capabilities into an existing simulation product. Validate the workflow developed in Phase I with historical data sets that show measurements of noncompliant components and full platforms tests performed with those components installed. Demonstrate the prototype in a lab or live environment.

VERSION 4

PHASE III DUAL USE APPLICATIONS: Complete development and perform final testing of a commercial grade application for use by platform level EMC engineers.

The simulation tool is suitable for electromagnetic compatibility evaluation of any civilian or military electronic system. Such system would be present on aircraft, ships, armored vehicles, space craft, automobiles, trucks, trains or even factories.

REFERENCES:

1. AFLCMC/EZSS. (2015, December11). MIL-STD-461G: Department of Defense interface standard: Requirements for the control of electromagnetic interference characteristics of subsystems and equipment Department of Defense. http://everyspec.com/MIL-STD/MIL-STD-0300-0499/MIL-STD-461G_53571/.
2. Joint Committee. (2010, December 1). MIL-STD-464C: Department of Defense interface standard: Electromagnetic environmental effects requirements for systems. Department of Defense. http://everyspec.com/MIL-STD/MIL-STD-0300-0499/MIL-STD-464C_28312/.

KEYWORDS: electromagnetic compatibility; electronic vulnerability; electromagnetic interference; radiated emissions; radiated susceptibility; modeling and simulation.

VERSION 4

N22A-T007 TITLE: Heteroepitaxy of Indium Phosphide-Based Quantum Cascade Lasers on Silicon Substrates

OUSD (R&E) MODERNIZATION PRIORITY: Cybersecurity; General Warfighting Requirements (GWR); Microelectronics

TECHNOLOGY AREA(S): Materials / Processes

OBJECTIVE: Design and develop a heteroepitaxy growth process that enables epitaxial growth of high-performance and high-reliability Indium Phosphide-based Quantum Cascade Lasers on silicon substrates.

DESCRIPTION: Monolithic integration of Quantum Cascade Lasers (QCLs) on silicon (Si) would enable a mechanically stable substrate that could take advantage of the best of both worlds: existing high-performance Si-based electronic and optical circuits (e.g., multiple-function, high-speed electronic circuitry; low-loss passive Si optical waveguides; active Si optical modulators and phase-shifters; etc.); and III-V semiconductor-based photonics (e.g., high-performance QCLs, and photo-detectors, etc.). Such compact systems with monolithically integrated mid-infrared sources with Si electronics have applications in infrared countermeasures, integrated transceivers for free-space optical communications, phased-array beam-steerable sources for laser detection and ranging, various passive- and active-optical sensing systems, etc. Moreover, two- and three-photon absorption losses are minimal in the mid-infrared wavelength range, thereby enabling low-loss optical transmission over integrated Si waveguides.

Fabry-Perot (FP) [Ref 1] and distributed-feedback (DFB) [Ref 2] QCLs emitting at 4.6 μm have been demonstrated by wafer bonding on Silicon-on-Nitride-on-Insulator (SONOI) substrates. Transfer printing on silicon-on-sapphire has also enabled monolithic integration of mid-IR QCL on Si [Ref 3]. However, precise alignment limits further advance of such techniques making them less cost-effective. Direct heteroepitaxial growth of QCLs on Si would, potentially, offer a substantially lower cost, large-scale wafer-scale manufacturable approach for optoelectronic integration via growing III-V epitaxial layers on much cheaper and larger Si substrates, as the mature complementary metal oxide semiconductor (CMOS) processing on large Si wafers have proven excellent throughput and yields, thereby offering the most competitive performance and economic advantages.

Nevertheless, heteroepitaxy of III-V semiconductor alloys on Si is quite challenging due to: (a) 8% lattice mismatch between Indium Phosphide (InP) and Si; (b) 50% mismatch in thermal coefficient of expansion; and (c) the formation of antiphase boundaries and domains, which can occur during the growth of polar III-V compounds on nonpolar Si substrates. To overcome these issues, metamorphic-buffer-layers (MBLs) are generally required, which can provide a low-defect-density growth platform of same lattice constant as InP, for the subsequent growth of QCL device structures. Such approaches have been recently successful in realizing high-performance, quantum-dot, active-region diode lasers operating in the near-infrared wavelength regions (1.3-1.55 μm) on Si substrates [Ref 4]. III-V growth on patterned V-grooves alleviates the problems of antiphase domain formation and acts as a filter for dislocations and stacking faults [Ref 5]. Indium Arsenide/Indium Aluminum Gallium Arsenide (InAs/InAlGaAs) quantum dots (QDs) have also shown to be effective threading-dislocation (TD) filters for InP MBLs [Ref 6]. However, there are very few studies reporting on direct growth of mid-IR QCLs on Si, in spite of the tremendous aforementioned size, performance, and cost advantages of the game-changing optoelectronic integration.

Molecular beam epitaxy-grown mid-IR QCLs, operating at low temperatures (170 K), have been demonstrated on Si substrates with 6°-miscut towards crystal orientation [111], by employing both a Germanium (Ge) buffer and a compositionally graded Aluminum Indium Arsenide (AlInAs) MBL to target the InP lattice constant [Ref 7]. MBLs, based on QD-dislocation filtering on exact (001) Si, have

VERSION 4

also been employed for the growth of QCL active regions by MOCVD [Ref 8]. Residual threading dislocation densities have been estimated to be rather high ($1E8 \text{ cm}^{-2}$ range) in both cases. The use of (001)-oriented Si substrates is key to achieving compatibility with Si-CMOS processing. Since QCLs are unipolar devices, they are expected to be insensitive to nonradiative recombination centers. However, dislocations can perturb the QCL superlattice active region and thus interfere with the coherent tunneling process. Thus, it is the objective of this project to reduce the residual-dislocation densities substantially and provide a low-surface roughness platform for the growth of high-performance, high-reliability QCLs on Si, equal with the performance specifications of 5 Watts continuous wave (CW) output at room temperature, wall-plug efficiency no less than 25%, and almost diffraction-limited beam quality with $M2 < 1.5$.

PHASE I: Develop a path for achieving low-defect density ($< 1 \times 1E7 /\text{cm}^2$) buffer layers on Si suitable for the growth of mid-IR QCLs. Complete the design of experiments for Phase II to establish room-temperature CW QCL operation on Si substrates. The Phase I effort will include prototype plans to be developed under Phase II.

PHASE II: Demonstrate room-temperature CW QCL operation on Si substrates employing direct-growth methods based on the epitaxial growth methods, and conditions, discovered in Phase I. The performance requirements of the QCL on Si substrates include 5 Watts CW output at room temperature, wall-plug efficiency no less than 25%, and almost diffraction-limited beam quality with $M2 < 1.5$.

PHASE III DUAL USE APPLICATIONS: Fabricate, test, and finalize the technology based on the design and demonstration results developed during Phase II. Develop a prototype using the finalized design and transition the technology with the final specifications for DoD applications in the areas of Directed Infrared Countermeasures (DIRCM), advanced chemicals sensors, and Laser Detection and Ranging (LIDAR).

The commercial sector can also benefit from this crucial, game-changing technology development of monolithic integration of QCLs with electronics on silicon substrate in the areas of detection of toxic gas environmental monitoring, non-invasive health monitoring and sensing, and industrial manufacturing processing.

REFERENCES:

1. Spott, A. et al. "Quantum cascade laser on silicon." *Optica*, 3(5), 545-551. <https://doi.org/10.1364/OPTICA.3.000545>.
2. Spott, A. et al. "Heterogeneously integrated distributed feedback quantum cascade lasers on silicon." *Photonics*, 3(2) 35. <https://doi.org/10.3390/photonics3020035>.
3. Jung, S., Kirch, J., Kim, J. H., Mawst, L. J., Botez, D., & Belkin, M. A. (2017, November 20). "Quantum cascade lasers transfer-printed on silicon-on-sapphire." *Applied Physics Letters*, 11(211102). <https://doi.org/10.1063/1.5002157>.
4. Jung, D., Herrick, R., Norman, J., Turnlund, K., Jan, C., Feng, K., Gossard, A. C., & Bowers, J. E. (2018, April). "Impact of threading dislocation density on the lifetime of InAs quantum dot lasers on Si." *Applied Physics Letters*, 112(15) 153507. <https://doi.org/10.1063/1.5026147>.
5. Li, Q. & Lau, K. M. (2017, December). "Epitaxial growth of highly mismatched III-V materials on (001) silicon for electronics and optoelectronics." *Progress in Crystal Growth and Characterization of Materials*, 63(4), 105-120. https://www.sciencedirect.com/science/article/pii/S0960897417300360?casa_token=F4B6QS3HyuEAAAAA:KxErkUfcp6Ea_kgbmGSswbghDfcnrd11b9nDVM6uLtBmLx_tL4p8IvK73W6Ko-k--u3iZKSg.

VERSION 4

6. Shi, B., Li, Q., & Lau, K. M. (2017, April 15). "Self-organized InAs/InAlGaAs quantum dots as dislocation filters for InP films on (001) Si." *Journal of Crystal Growth*, 464, 28–32. <https://doi.org/10.1016/j.jcrysgro.2016.10.089>.
7. Go, R. et al. (2018). "InP-based quantum cascade lasers monolithically integrated onto silicon." *Optics Express*, 26(17), 22389-22393. <https://doi.org/10.1364/OE.26.022389>.
8. Rajeev, A. et al.(2018, October 10). "III-V superlattices on InP/Si metamorphic buffer layers for 4.8 μm quantum cascade lasers." *Physica Status Solidi*, 216(1). <https://doi.org/10.1002/pssa.201800493>.

KEYWORDS: Silicon; quantum cascade laser; QCL; monolithic integration; complementary metal oxide semiconductor; CMOS; heteroepitaxial; distributed feedback

VERSION 4

N22A-T008 TITLE: Smart Image Recognition Sensor with Ultralow System Latency and Power Consumption

OUSD (R&E) MODERNIZATION PRIORITY: General Warfighting Requirements (GWR);Microelectronics;Quantum Science

TECHNOLOGY AREA(S): Electronics

OBJECTIVE: Develop a novel smart visual image recognition system that has intrinsic ultralow power consumption and system latency, and physics-based security and privacy.

DESCRIPTION: Image-based recognition in general requires a complicated technology stack, including lenses to form images, optical sensors for opto-to-electrical conversion, and computer chips to implement the necessary digital computation process. This process is serial in nature, and hence, is slow and burdened by high-power consumption. It can take as long as milliseconds, and require milliwatts of power supply, to process and recognize an image. The image that is digitized in a digital domain is also vulnerable to cyber-attacks, putting the users' security and privacy at risk. Furthermore, as the information content of images needs to be surveilled and reconnoitered, and continues to be more complex over time, the system will soon face great challenges in system bottleneck regarding energy efficiency, system latency, and security, as the existing digital technologies are based on digital computing, because of the required sequential analog-to-digital processing, analog sensing, and digital computing.

It is the focus of this STTR topic to explore a much more promising solution to mitigate the legacy digital image recognition latency and power consumption issues via processing visual data in the optical domain at the edge. This proposed technology shifts the paradigm of conventional digital image processing by using analog instead of digital computing, and thus can merge the analog sensing and computing into a single physical hardware. In this methodology, the original images do not need to be digitized into digital domain as an intermediate pre-processing step. Instead, incident light is directly processed by a physical medium. An example is image recognition [Ref 1], and signal processing [Ref 2], using physics of wave dynamics. For example, the smart image sensors [Ref 1] have judiciously designed internal structures made of air bubbles. These bubbles scatter the incident light to perform the deep-learning-based neuromorphic computing. Without any digital processing, this passive sensor can guide the optical field to different locations depending on the identity of the object. The visual information of the scene is never converted to a digitized image, and yet the object can be identified in this unique computation process. These novel image sensors are extremely energy efficient (a fraction of a micro Watt) because the computing is performed passively without active use of energy. Combined with photovoltaic cells, in theory, it can compute without any energy consumption, and a small amount of energy will be expended upon successful image recognition and an electronic signal needs to be delivered to the optical and digital domain interface. It is also extremely fast, and has extremely low latency, because the computing is done in the optical domain. The latency is determined by the propagation time of light in the device, which is on the order of no more than hundreds of nanoseconds. Therefore, its performance metrics in terms of energy consumption and latency are projected to exceed those of conventional digital image processing and recognition by up to at least six orders of magnitude (i.e., 100,000 times improvement). Furthermore, it has the embedded intrinsic physics-based security and privacy because the coherent properties of light are exploited for image recognition. When these standalone devices are connected to system networks, cyber hackers cannot gain access to original images because such images have never been created in the digital domain in the entire computation process. Hence, this low-energy, low-latency image sensor system is well suited for the application of 24/7 persistent target recognition surveillance system for any intended targets.

VERSION 4

In summary, these novel image recognition sensors, which use the nature of wave physics to perform passive computing that exploits the coherent properties of light, is a game changer for image recognition in the future. They could improve target recognition and identification in degraded vision environment accompanied by heavy rain, smoke, and fog. This smart image recognition sensor, coupled with analog computing capability, is an unparalleled alternative solution to traditional imaging sensor and digital computing systems, when ultralow power dissipation and system latency, and higher system security and reliability provided by analog domain, are the most critical key performance metrics of the system.

PHASE I: Develop, design, and demonstrate the feasibility of an image recognition device based on a structured optical medium. Proof of concept demonstration should reach over 90% accuracy for arbitrary monochrome images under both coherent and incoherent illumination. The computing time should be less than 10 μ s. The throughput of the computing is over 100,000 pictures per second. The projected energy consumption is less than 1 mW. The Phase I effort will include prototype plans to be developed under Phase II.

PHASE II: Design image recognition devices for general images, including color images in the visible or multiband images in the near-infrared (near-IR). The accuracy should reach 90% for objects in ImageNet. The throughput reaches over 10 million pictures per second with computation time of 100 ns and with an energy consumption less than 0.1 mW. Experimentally demonstrate working prototype of devices to recognize barcodes, handwritten digits, and other general symbolic characters. The device size should be no larger than the current digital camera-based imaging system.

PHASE III DUAL USE APPLICATIONS: Fabricate, test, and finalize the technology based on the design and demonstration results developed during Phase II, and transition the technology with finalized specifications for DoD applications in the areas of persistent target recognition surveillance and image recognition in the future for improved target recognition and identification in degraded vision environment accompanied by heavy rain, smoke, and fog.

The commercial sector can also benefit from this crucial, game-changing technology development in the areas of high-speed image and facial recognition. Commercialize the hardware and the deep-learning-based image recognition sensor for law enforcement, marine navigation, commercial aviation enhanced vision, medical applications, and industrial manufacturing processing.

REFERENCES:

1. Khoram, E., Chen, A., Liu, D., Ying, L., Wang, Q., Yuan, M., & Yu, Z. (2019). "Nanophotonic media for artificial neural inference." *Photonics Research*, 7(8), 823-827.
<https://doi.org/10.1364/PRJ.7.000823>.
2. Hughes, T. W., Williamson, I. A., Minkov, M., & Fan, S. (2019). "Wave physics as an analog recurrent neural network." *Science advances*, 5(12), eaay6946.
<https://doi.org/10.1126/sciadv.aay6946>.

KEYWORDS: Image recognition; wave mechanics; low latency; passive computing; sensors; deep learning

VERSION 4

N22A-T009 TITLE: DIGITAL ENGINEERING - Sonar Dome Anti-Fouling Tracking and Prediction Tool

OUSD (R&E) MODERNIZATION PRIORITY: General Warfighting Requirements (GWR)

TECHNOLOGY AREA(S): Information Systems

OBJECTIVE: Develop a capability to collect, analyze, and predict levels of Tributyltin Oxide (TBTO) in deployed sonar domes.

DESCRIPTION: A sonar dome protects the acoustic transducers, to reduce noise and enable optimal sonar performance. Crucial to its function is that the dome does not foul. Historically, this has been done by imbuing sonar domes with Tributyltin Oxide (TBTO) during the manufacturing process. Research to prevent fouling has not developed an alternative that is qualified for the domes on surface combatants. Even when a new anti-fouling method may be identified, there will be scores of sonar domes imbued with TBTO, with decades of remaining service. A combatant is at sea for about eight years before maintenance carried out at dry dock. Conventional, off-the-shelf antifouling approaches do not work with sonar domes, because they are made of rubber.

The Naval Research Laboratory (NRL) has recently developed a rapid, non-destructive, and inexpensive method to measure TBTO (or other anti-fouling systems) in sonar domes while a ship is dry docked. This will provide, for the first time, the data necessary for a nuanced understanding of the anti-fouling efficacy, throughout its service life.

The Navy seeks technology that will enable central management of these measurements from USN sonar domes that are deployed to locations and environments around the world, together with an ontological framework to record pertinent information about the sonar dome, such as manufacturing details and service life history. It is also desired that the architecture of the proposed technology accommodate a methodology for predicting anti-fouling life and updated algorithms as data supports algorithm refinement. Development of an initial predictive algorithm could fall within the scope of this STTR topic.

The Navy seeks a centralized capability for collecting this information, populating an ontological framework with pertinent data (such as sonar dome manufacturing details and service life history) for each measurement, and predicting future TBTO levels to understand both:

1. When sonar domes will need to be replaced due to depletion of TBTO.
2. When it may be appropriate to reduce the amount of TBTO (or future anti-foulant) used in new-construction sonar domes with changes in dome material or anti-foulant.

The centralized capability will enable the Navy to minimize maintenance while also minimizing harm to the marine environment.

The framework described herein must include:

- A method to capture data from a measurement tool for utilization in a Fleet-wide physics-based model designed for modular updating manually via future re-assessment of an updated database.
- A graphical user interface (GUI) that displays tracked values of interest.

Examples of potential elements to this ontology are:

- Measured anti-foulant loading remaining in coating.
- Models of TBTO degradation as a function of time and combatant travel profile.
- Predicted remaining lifespan of sonar dome TBTO based on measurements and predicted travel profile.

VERSION 4

- Updated physics-based model calculations.

Any additional ontological elements that would improve the model would be welcome.

The physics-based model shall also incorporate:

1. Input parameters, including service conditions, that may vary over a deployment. Variables of primary considerations are surface ocean temperature and salinity, but others may be added.
2. Capability to change the input properties, to accommodate updated material specifications and other improvements.

PHASE I: Develop a concept for a physics-based database and GUI for diffusion from a sonar dome that meets all the parameters in the Description. Demonstrate the concept is feasible through analysis, simulation, and modelling. Preliminary experimental data will be provided by NRL. The Phase I Option, if exercised, will include the initial design specifications and a capabilities description to build a prototype solution in Phase II.

PHASE II: Develop and deliver a prototype physics-based database and GUI for the TBTO collection and prediction capability. Demonstrate the prototype meets the required range of desired performance attributes given in the Description. Feasibility will be demonstrated through system performance with information from initial TBTO measurements that will be collected. Develop a Phase III commercialization plan.

PHASE III DUAL USE APPLICATIONS: Support the Navy in transitioning the technology for Navy use as software to collate, analyze, and manage TBTO data collected and tested via a hardware measurement capability maintained by IWS 5.0. Demonstrate and report on performance during laboratory testing.

This technology can be used in a wide range of products where measurements of toxins or other material dopants of specified loadings are collected and predictions of future state are dependent on numerous variables which are not entirely dependent on one another. With the appropriate modifications, it may be used to monitor performance of commercial antifoulant systems, particularly when a new system is being adopted. The technology would be of greatest use in cases where environmental impact of a substance is of national or global concern, particularly in water / wastewater management or aquaculture settings.

REFERENCES:

1. Omae, Iwao. (2003). "Organotin Antifouling Paints and Their Alternatives." Applied Organometallic Chemistry, Vol. 17, n2 (200302), . 81 - 105. <https://www.worldcat.org/title/organotin-antifouling-paints-and-their-alternatives/oclc/4633838388>.
2. Donnelly, Bradley et al. (2019) "Effects of Various Antifouling Coatings and Fouling on Marine Sonar Performance. Polymers." Polymers Vol. 11, Issue 4, 663. <https://www.mdpi.com/2073-4360/11/4/663>.
3. "AN/SQQ-89(V) Undersea Warfare / Anti-Submarine Warfare Combat System." United States Navy Fact File, 24 March 2021. <https://www.navy.mil/Resources/Fact-Files/Display-FactFiles/Article/2166784/ansqq-89v-undersea-warfare-anti-submarine-warfare-combat-system/>.

KEYWORDS: Sonar dome; tributyltin oxide; TBTO; anti-fouling for sonar domes; ontological framework; predicting anti-fouling life; water management; wastewater management; aquaculture

VERSION 4

N22A-T010 TITLE: Kilowatt Class-k Fiber Optical Isolator for Submarine High Energy Laser Amplifier

OUSD (R&E) MODERNIZATION PRIORITY: Directed Energy (DE)

TECHNOLOGY AREA(S): Weapons

OBJECTIVE: Design and develop a compact and robust fiber optical isolator for kW class fiber lasers/amplifiers.

DESCRIPTION: Optical isolators transmitting light only in one direction while blocking light in the opposite direction have been extensively used to protect laser systems from the influence of the backward light. Fiber lasers have seen significant developments during the last two decades and kW class fiber lasers have been deployed in different platforms for DoD applications. This has created demand for high power compact and robust optical isolators that can be used to protect these kW class fiber lasers. Commercial free-space bulk optical isolators capable of handling optical average powers up to kW level are becoming available. However, the packaging volume, thermal resistance, reliability, and even the power handling cannot meet most DoD applications. Fiber-coupled or fiber-based optical isolators have the advantages of small format, easy operation, and high robustness while exhibiting the promise of high-power handling. Currently, the power handling capability of fiber-coupled isolators is limited to 100 W. This STTR topic seeks innovative device design, advanced Faraday material, new magnet material, and novel power polarizers that can be combined for the development of kW class fiber optical isolators. This topic supports the development of a prototype with the parameters listed below at the end of Phase II:

- Operating Wavelengths: 1 μ m, 1.55 μ m, and 2 μ m • Average Power handling: Threshold 3 kW; Objective 5 kW per amplifier
- Bandwidth: Threshold 20 nm; Objective 50 nm
- Insertion Loss: Threshold < 1 dB; Objective < 0.5 dB
- Isolation: Threshold > 30 dB; Objective > 40 dB
- Polarization extension ratio (FER) > 30 dB
- Reliability: Lifetime > 5000 hours
- Thermo Electric (TEC) or Water cooling preferred

Under the Phase II Option II, if exercised, a prototype kW class Fiber optic isolator will be delivered to a Navy lab to evaluate the performance of the system in terms of its optical isolation > 40 dB for HEL system.

PHASE I: Develop a concept that uses the Faraday material, magnet material, and polarizers for a best-performance optical isolator construction that can be used for kW class fiber lasers. Demonstrate the power handling scalability of the new isolator material and device. The isolator concepts will be designed to meet the performance capabilities identified in the Description section. Demonstrate the feasibility of the concept to meet the parameters listed in the Description through modeling, simulation, 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 deliver a prototype based on the results of Phase I, supporting the parameters listed in the description. Optimize the design and development of the Phase I kW class optical isolator to a prototype compact and robust fiber optical isolators for kW class fiber lasers.

VERSION 4

Deliver a prototype kW class Fiber optic isolator to a Navy lab to evaluate the performance of the system in terms of its optical isolation > 40 dB for HEL system as described in the Phase II SOW. Any test data collected at Navy facilities shall be Government use only.

PHASE III DUAL USE APPLICATIONS: Transition of kW class Fiber optic isolator to Navy use for the purpose of HEL technology integration at 1 to 2 μm MW class laser. Identify the final kW class fiber isolator product and describe how the company will support transition to Phase III. Ultimately, the HEL system will be deployed in a submarine or other Navy platform advancing future Navy warfighting capabilities.

Fiber optical isolators with high power handling capability can be used in various HEL laser systems for DoD and industrial applications such as welding, cutting, soldering, marking, cleaning, and material processing.

REFERENCES:

1. Khazanov, E.A. "Slab-based Faraday isolators and Faraday mirrors for 10-kW average laser power", *Applied Optics*, Vol. 43, Issue 9, 1907 (2004).
2. Snetkov, I.L.; Voitovich, A.V.; Palashov, O.V. and Khazanov, E.A. "Review of Faraday isolators for kilowatt average power lasers," *IEEE Journal of Quantum Electronics*, Vol. 50, Issue 6, 434 (2014).
3. Turner, E.H. and Stolen, R.H. "Fiber Faraday circulator or isolator", *Optics Letters*, Vol. 6, Issue 7, 322 (1981).
4. Sun, L. et al. "Compact all-fiber optical Faraday components using 65-wt%-terbium-doped fiber with a record Verdet constant of -32 rad/(Tm)", *Optics Express*, Vol. 18, Issue 12, 12191 (2010).
5. Sun, L. et al., "All-fiber optical isolator based on Faraday rotation in highly terbium-doped fiber", *Optics Letters*, Vol. 35, Issue 5, 706 (2010).

KEYWORDS: Optical isolator; fiber isolator; kW class fiber lasers; Faraday rotator; magneto-optical material; polarizer

VERSION 4

N22A-T011 TITLE: Shipboard Creepage and Clearance Analysis

OUSD (R&E) MODERNIZATION PRIORITY: General Warfighting Requirements (GWR)

TECHNOLOGY AREA(S): Electronics

OBJECTIVE: Develop test equipment to measure electrical properties related to shipboard environmental factors that affect creepage and clearance in Medium Voltage (MV) Naval electrical power systems.

DESCRIPTION: Naval electrical power systems and associated high power combat systems are increasingly employing Medium Voltage (MV) power in the range of 1 to 35 kiloVolt (kV) AC or DC. Creepage and clearance requirements are a major driver in power density of MV equipment. Clearance is the shortest "air" distance between two exposed conductors while creepage is the distance along insulation surfaces between two exposed conductors. Setting these values too conservatively results in excessively large equipment; setting them too low results in equipment failure due to flashover. MVDC requirements have not yet been established, and the appropriateness of the MVAC requirements is not known. MVAC requirements are based on terrestrial commercial standards which have never been validated to apply to the marine environment. Naval ships have experienced arcing fault flashovers that have caused significant amounts of damage and lost operational time.

The most significant factor for establishing safe clearance distances is the electrical properties of the air, which is affected by pollutants, salts, and other air contaminants. The air in different spaces onboard ship is certain to have varying electrical properties.

Similarly, the most significant factor for establishing safe creepage distances is the electrical properties of the surface contaminants on insulators, which will vary significantly throughout the ship. Currently, there are no Navy or commercial products that are designed to measure creepage or clearance within a naval ship environment.

The Navy seeks a portable testing apparatus to measure the electrical properties of air and surface contaminants onboard a naval ship at a threshold level of 20kV and objective of 35kV. A method is also needed to use these measurements as Objective Quality Evidence (OQE) for developing safe creepage and clearance requirements for inclusion in applicable equipment specifications and military standards. The portable testing apparatus measurements shall be accurate and repeatable enough to enable the Navy to employ the method to establish the creepage and clearance requirements.

The Navy anticipates using multiple test apparatuses to create an initial survey of shipboard spaces over an extended period of time in operational conditions and industrial conditions. Following initial surveys, the Navy intends to employ the test apparatus in both prognostic and forensic procedures to understand the shipboard environment in specific ships.

PHASE I: Provide a concept design for an apparatus that measures the electrical properties of air and surface contaminants onboard a naval vessel. Provide evidence, either through experimentation or simulation, that the concept design is feasible. Also provide a method to use measurements from the apparatus as Objective Quality Evidence (OQE) for developing safe creepage and clearance requirements for inclusion in applicable equipment specifications and military standards. The Phase I Option, if exercised, will include the initial design specifications and capabilities description to build a prototype apparatus in Phase II.

PHASE II: Provide, demonstrate, and deliver an initial prototype apparatus that measures the electrical properties of air and surface contaminants onboard a naval vessel. Demonstrate the method to use

VERSION 4

measurements from the prototype apparatus as OQE for developing safe creepage and clearance requirements for inclusion in applicable equipment specifications and military standards. Based on feedback from demonstrations of the initial prototype apparatus, incorporate improvements in the apparatus design and produce two additional prototype apparatuses. Demonstrate these two prototypes function as intended and deliver to the U.S. Government.

PHASE III DUAL USE APPLICATIONS: Support the Navy in transitioning the technology to Navy use. Update the prototype design to a final production configuration and develop supporting training documentation. The Government anticipates using multiple test apparatuses to create an initial survey of shipboard spaces over an extended period of time in operational conditions and industrial conditions. Following initial surveys, the Government intends to employ the test apparatus in both prognostic and forensic procedures to understand the shipboard environment in specific ships.

This device should also prove useful in both the naval and commercial marine sectors to ensure the air and surface contaminants onboard ship are not more severe than for contaminants the shipboard equipment was designed for.

REFERENCES:

1. Damle, Tushar; Park, Chanyeop; Ding, Jeffrey; Cheetham, Peter; Bosworth, Matthew; Steurer, Mischa; Cuzner, Robert and Graber, Lukas. "Experimental setup to evaluate creepage distance requirements for shipboard power systems." 2019 IEEE Electric Ship Technologies Symposium, Arlington VA, August 14-16, 2019. <https://ieeexplore.ieee.org/abstract/document/8847827>.
2. Kaaiye, Sharif F. and Nyamupangedengu, Cuthbert. "Comparative study of AC and DC inclined plane tests on silicone rubber (SiR) insulation." The Institution of Engineering and Technology, 20 April 2017. https://www.researchgate.net/publication/316518121_A_Comparative_Study_of_AC_and_DC_Inclined_Plane_Tests_on_Silicone_Rubber_SiR_Insulation.
3. "IEEE Recommended Practice for 1 kV to 35 kV Medium-Voltage DC Power Systems on Ships." IEEE Industry Applications Society and IEEE Power Electronics Society, IEEE Std 1709-2018, 27 September 2018. <https://ieeexplore.ieee.org/document/8569023>.

KEYWORDS: Creepage; Clearance; Air Contamination Electrical Properties; Surface Contamination Electrical Properties; Medium Voltage; MV; MVAC; MVDC; Flashover

VERSION 4

N22A-T012 TITLE: Survivable Minefield Mission Data Module

OUSD (R&E) MODERNIZATION PRIORITY: General Warfighting Requirements (GWR)

TECHNOLOGY AREA(S): Ground / Sea Vehicles

OBJECTIVE: Develop a hardened data module that can withstand blast effects from detonation of underwater explosives while preserving accumulated mission essential data from Unmanned Undersea Vehicles (UUV) and Remotely Operated Vehicles (ROV) systems.

DESCRIPTION: The Maritime Expeditionary MCM Unmanned Undersea Vehicle (MEMUUV) and Maritime Expeditionary Standoff Response (MESR) systems provide Navy Expeditionary forces with specialized UUV and ROV systems that deploy for search, detection, localization, neutralization and disposal of naval mines and underwater improvised explosive devices (IEDs). Mines and IEDs are often detonated by acoustic and magnetic noise from ships and subsurface platforms in the vicinity and by UUVs and ROVs conducting time-intensive mine and IED clearance operations in undersea environments. Although UUV and ROV platforms are not deployed as expendable platforms, they are susceptible to and not sufficiently hardened against inadvertent arming and detonation of a mine or IED while performing clearance missions. The blast effects from an inadvertent detonation may result in loss of essential mission data accumulated during hours of UUV/ROV operations. Mission data collected during a single, 20-hour sortie may result in an accumulation of up to 10 terabytes of data. Wireless data transfer bandwidth limitations for expeditionary platforms (typically between 5 kilobits per second up to 150 megabits per second) preclude real-time data exfiltration from the platforms; most mission essential information must be downloaded post-mission.

This STTR topic seeks to develop a compact, survivable “black box” mission module to collect mission data prior to a detonation. The solution must preserve the data and allow system operators to retrieve the data post-detonation. Data preservation can occur either by retrieval of the module or via secure wireless data transfer following an underwater explosive detonation event occurring within 10 meters of a 2500-pound TNT-equivalent net explosive weight (NEW) object on the seabed in up to 300 meters of water depth, which could result in total loss of a UUV or ROV platform. The module must have interface capabilities to facilitate recovery or autonomous data transfer and must be designed to protect the module and information from recovery by adversaries.

Aircraft flight recorders are not suitable in size, nor in the types of mission data they collect as a survivable mission module for undersea platforms; however, the basic concept is the same. There are currently no known solutions for preservation of mission essential data from UUV missions. Mission data collected on objects in the water column and on the seabed, including accumulated geo-referenced imagery up to the point where a mine explosion which destroys or incapacitates a UUV, is important for time constrained clearance operations. Proposed concepts must be compact for integration into small, volume-constrained UUV and ROV systems without adversely impacting trim, balance, or hydrodynamic performance of the platform. Size, weight and power (SWaP) constraints will vary depending on design concept. A self-contained module should not exceed 20 cubic inches in volume (e.g., a ~1 inch diameter x 6 inches long cylinder). Weight/mass should enable a neutrally buoyant solution in seawater. For a completely self-contained hardware solution mounted externally to a platform, a neutrally buoyant, hydrodynamic form factor must be sufficiently small and streamlined as not to add drag or impact platform endurance while maneuvering. Additionally, concepts must be powered independently. Power endurance requirements vary based on the concept for data retrieval; however, proposed solutions should have sufficient power and longevity to enable recovery while also being able to erase data if not recovered. If lithium chemistry batteries are proposed as a component of the independent power system design, solutions should incorporate batteries which have previously been certified for Navy shipboard

VERSION 4

use, storage and transportation in accordance with NAVSEA Instruction 9310.1, or should include evaluation of battery safety suitability within the scope of the proposed concept validation. To align for successful future transition following a successful demonstration, concepts should consider hardware and software solutions that will either satisfy or be easily adaptable to satisfy cyber security compliance for DoD/Navy use in accordance with DoD Instruction 8500.1 and Department of the Navy Cyber Security Policy compliance (SECNAVINST 5239.3C of 2 May 16).

Testing of the key performance parameters and key system attributes will be performed in a relevant environment to verify that the task objectives were met. To demonstrate some aspects of the technical performance (e.g., survivability of large explosive charges), modeling and simulation coupled with technical analysis is deemed an acceptable approach.

PHASE I: Develop an innovative concept for a blast-survivable mission data module that meets the design constraints listed in the description. Establish feasibility by modeling and simulation, analysis, and/or laboratory experimentation, as appropriate.

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 a prototype of the survivable data module compatible for demonstration and characterization of key performance parameters, key system attributes, and objectives. Conduct testing of the key performance parameters and key system attributes in a relevant environment to verify that the task objectives were met. To demonstrate some aspects of the technical performance (e.g., survivability of large explosive charges), consider modeling and simulation coupled with technical analysis. Based on lessons learned in Phase II through the prototype demonstration, a substantially complete design of the data module should be completed and delivered that would be expected to pass Navy qualification testing.

PHASE III DUAL USE APPLICATIONS: Support the Navy in transitioning the technology to Navy use through system integration and qualification testing of a survivable mission data module. The final survivable minefield mission data module product will need to conform to all specifications and requirements. A full-scale prototype will be operationally tested at sea and certified by the Navy.

Innovative concepts offer a broader opportunity for use of a “black box” solution across many military activities collecting and transporting high value sensitive data, on autonomous subsurface and surface platforms, at risk of being destroyed in the course of their mission.

REFERENCES:

1. Keevin, Thomas and Hempen, Gregory. “The Environmental Effects of Underwater Explosives with Methods to Mitigate Impacts.” Army Corps of Engineers, St Louis District, August 1997. <https://denix.osd.mil/nr/otherconservationtopics/coastalandoceanresources/marine-mammals/the-environmental-effects-of-underwater-explosions-with-methods-to-mitigate-impacts/>.
2. Secretary of the Navy Innovation Awards; “The Expeditionary MCM (ExMCM) Company: The Newest Capability in U.S. Navy Explosive Ordnance Disposal (EOD) Community.” July 2017. <https://www.secnav.navy.mil/innovation/Documents/2017/07/ExMCM.pdf>.
3. Secretary of the Navy Instruction 5239.3C dated 2 May 2016. (Department of the Navy Cyber Security Policy).
4. NAVSEA Instruction 9310.1B dated 13 Jun 1991 (Naval Lithium Battery Safety Program).

KEYWORDS: Mine Countermeasures; Survivability; Unmanned Undersea Vehicles; Remotely Operated Vehicles; Mines; Improvised Explosive Devices.

VERSION 4

N22A-T013 TITLE: Damage-Free High Power Emission from Indium Phosphide-Based Solid State Waveguides in the Long Wave Infrared

OUSD (R&E) MODERNIZATION PRIORITY: Directed Energy (DE)

TECHNOLOGY AREA(S): Sensors

OBJECTIVE: Develop a capability that enables reliable emission of high power, single lateral mode, long wave infrared laser beams from Indium Phosphide-based solid state waveguides.

DESCRIPTION: Infrared (IR) photonic integrated circuits, especially those incorporating solid state laser diodes operating in the long wave infrared (LWIR) band, often employ the Indium Phosphide (InP) III-V semiconductor system. Optical signals are transmitted in solid state waveguides fabricated directly in epilayers grown on the InP substrate, which are usually designed for light propagation in a single lateral mode. In many applications, the optical power may be emitted to free space at an edge facet or from some other surface. However, the emitted power is sometimes quite high and the maximum power density at the center of the beam can be exceedingly intense. Furthermore, the efficient extraction of optical power from the facet is typically aided by the deposition of an anti-reflection (AR) coating that minimizes the reflection of light back into the waveguide.

Current InP-based waveguides operating in the 9-11 μm spectral band are susceptible to optical damage at the AR-coated output facet, which limits the maximum continuous wave or average power that can be emitted to less than 2 W. This limitation severely constrains the usefulness of technologies that could otherwise enable higher levels of integration, such as beam combining by an arrayed waveguide grating (AWG). Therefore, the Navy needs an LWIR InP-based waveguide and output coupling technology that reliably increases the maximum power that can be emitted to at least 10 W.

The goal is to demonstrate damage-free operation in both the waveguide and at the output interface over long term operation. Propagation in the waveguide shall be in a single lateral mode and the transmission at the output surface should be at least 90%. The output should be in a nearly diffraction-limited beam with maximum M2 factor of 2.0 (M2 defined according to ISO Standard 11146). The output interface is considered to be to the atmosphere, at sea-level.

Methods for injecting optical power into the waveguide for testing are not a subject of this effort. However, accurate measurement of the output coupling efficiency is expected. In addition, the ability to vary the transmitted power, incrementally or continuously, in order to “test to failure” is highly desirable. Prototype solutions may be demonstrated at any wavelength (or combination of multiple wavelengths) between 9 and 11 μm . However, test wavelengths should be chosen for maximum atmospheric transmission in order to minimize uncertainties in testing and all prototypes should be tested at the same wavelengths. While testing at all wavelengths across the LWIR band is not required, the solution should be suitable for applications that combine multiple LWIR wavelengths spanning the entire upper LWIR band (8-14 μm) in the same beam. Solutions that are “tuned” to specific wavelengths or narrow bands are unacceptable.

Potential solutions may include improvements in ridge geometry, improved AR coatings with lower absorption in the LWIR, tapering of the waveguide along one or both axes, improved heat dissipation at the output surface, surface-emitting (versus edge-emitting) geometries, or other solutions employing innovative architectures and materials. However, acceptable solutions must be capable of fabrication through normal integrated circuit manufacturing processes and work flow. The objective is to develop a technology that can be incorporated into multiple photonic integrated circuit designs. Therefore, coatings

VERSION 4

and bonding processes are acceptable but solutions that require the addition of “off-chip” elements or require labor-intensive “touch time” assembly are unacceptable. Assembly steps that are performed solely to incorporate diagnostic elements or are performed for fixturing or calibration and do not form a part of the actual technical solution are acceptable. For example, process and assembly steps required to inject optical power into the device for demonstration and testing are not considered to be part of the solution.

As this effort is assumed to be necessarily iterative in nature, it is expected that multiple prototype devices will be produced during its course. In addition, a staged approach in which prototypes capable of 5 W output are first demonstrated and then extensively tested over long term cyclical operation (a minimum of 100 hours of operation with 50 on-off cycles) to assess cumulative damage effects is highly desirable. Testing will be performed in a laboratory environment provided by the proposer. At the end of the effort, the five best performing prototype devices (which have not been “tested to failure”) shall be delivered to the Naval Research Laboratory (NRL). Any specialized equipment (e.g., power sources, test equipment and test fixtures, calibration standards, etc.) specifically built or acquired for testing of the devices, along with test data on the devices, shall also be delivered to NRL.

PHASE I: Develop a concept for a high-power LWIR InP-based waveguide technology with transmission, out-coupling, and power-handling characteristics that meet the objectives stated in the Description. Define the architecture and materials required for the concept, and demonstrate its feasibility for meeting the Navy need. Feasibility shall be demonstrated by a combination of analysis, modelling, and simulation. Identify key manufacturing steps and challenges. Define the test configuration, including the method for injecting and measuring the power introduced to the waveguide. The Phase I Option, if exercised, will include formulation of the device specification, test specifications, interface requirements, and the manufacturing requirements necessary to build and evaluate device prototypes in Phase II.

PHASE II: Develop and deliver a prototype high-power LWIR InP-based waveguide transmission and out-coupling technology based on the concept, analysis, architecture, and specifications resulting from Phase I. Demonstrate that the prototype waveguides operate without damage as detailed in the Description. Demonstrate the technology through production and testing of prototypes in a laboratory environment provided by the proposer. It is expected that multiple prototypes will be produced during execution of this Phase as the design process is assumed to be necessarily iterative in nature. At the conclusion of Phase II, five samples employing the best-performing prototype solution (or solutions) shall be delivered to the Naval Research Laboratory, along with complete test data and any specialized equipment needed to replicate testing.

PHASE III DUAL USE APPLICATIONS: Support the Navy in transitioning the technology for Government use. Identify specific manufacturing steps and processes that require further development, mature those steps and processes, establish a hardware configuration baseline, create production-level documentation, and insert the technology into specific semiconductor fabrication processes. Assist the government in integrating the technology into specific photonic integrated circuit designs meeting requirements supplied by the government and transitioning those designs into production.

Commercial, and scientific applications include use in laser spectroscopy for remote detection of chemicals and explosive compounds, and free-space optical communications (backhaul networks).

REFERENCES:

1. Hitaka, M., et al. “Stacked quantum cascade laser and detector structure for a monolithic mid-infrared sensing device.” *Applied Physics Letters*, Vol. 115, Issue 16, October 2019. <https://aip.scitation.org/doi/full/10.1063/1.5123307>.

VERSION 4

2. Sin, Y., et al. "Catastrophic Degradation in Quantum Cascade Lasers Emitting at 8.4 μm ." 2014 IEEE Photonics Society Summer Topical Meeting Series, Montreal, 14-16 July 2014. <https://ieeexplore.ieee.org/document/6902994>.
3. Phillips, Mark C., et al. "Standoff detection of chemical plumes from high explosive open detonations using a swept-wavelength external cavity quantum cascade laser." Journal of Applied Physics 128, Issue 16, 27 July 2020. <https://aip.scitation.org/doi/abs/10.1063/5.0023228>.
4. Johnson, Stephen, et al. "High-speed free space optical communications based on quantum cascade lasers and type-II superlattice detectors." Proceedings of the SPIE, Quantum Sensing and Nano Electronics and Photonics XVII: 11288, San Francisco, 2-6 February 2020. <https://www.spiedigitallibrary.org/conference-proceedings-of-spie/11288/1128814/High-speed-free-space-optical-communications-based-on-quantum-cascade/10.1117/12.2548348.short>.

KEYWORDS: Long Wave Infrared; Anti-Reflection Coating; Beam Combining; Indium Phosphide; Solid State Waveguides; Photonic Integrated Circuits.

VERSION 4

N22A-T014 TITLE: Visible to Near Infrared Laser Array with Integral Wavelength Beam Combining

OUSD (R&E) MODERNIZATION PRIORITY: Directed Energy (DE)

TECHNOLOGY AREA(S): Sensors

OBJECTIVE: Develop an array of visible to near-infrared (VNIR) lasers with integral (on-chip) wavelength beam combining for a single, high quality output beam.

DESCRIPTION: Many threats to surface ships employ imagers and detectors operating in the visible to near-infrared (VNIR) band. These include lethal threats as well as aircraft and unmanned aerial systems performing routine surveillance. To combat these threats, shipboard countermeasures are needed and, for the most sophisticated threats, lasers are the fundamental component of the electro-optic (EO) countermeasure suite. For compactness and simplified power and control circuitry, semiconductor lasers are a highly attractive solution. However, in order to achieve the output powers required, multiple individual laser diodes must be combined in a laser “module” with a single output. This solution also provides spectral coverage across the wavelength band (or a specified portion of the band) as laser diodes of different wavelengths are combined ? a highly desirable feature for countermeasure applications. However, the architecture presents a considerable cost in manufacturing as the exacting tolerances required result in high component costs and the assembly process is highly labor-intensive. The assembly cost of the laser diode combiner typically accounts for as much as half the cost of the finished laser module.

Other possible laser sources are either bulky, even more expensive, or have other undesirable characteristics such as multi-mode operation. For example, some high brightness semiconductor lasers require an additional pump source or other free-space optics which increases size and cost. Other solutions involve frequency doubling to produce single wavelength output that would still have to be combined with the output from other lasers to achieve spectral coverage. Currently, there is no off-the-shelf laser source that can produce any significant power (> 1.5 W) across the VNIR waveband at an affordable price and in a sufficiently compact form factor.

The Navy needs compact and affordable laser sources in the VNIR band, specifically the wavelengths covering 0.5 through 0.85 microns. In this context, a “laser source” is understood as being distinct from a simple laser, in that the laser source combines the output of multiple individual lasers into a single output beam. In the case of the laser module described above, this is done through the assembly, integration, and alignment of multiple individual laser diodes with external optical components that perform the beam combining. However, it may also be done by integration of the combining optics directly on the same semiconductor substrate that contains the laser diodes, creating a photonic integrated circuit that is effectively a miniature laser “module” on a chip. With the exception of packaging and alignment of the output optics, this “on-chip” combining eliminates almost all of the assembly steps required for the discrete-component laser module. And while the cost of semiconductor fabrication increases, the overall cost of the resulting laser source can be significantly reduced, provided the technical challenges of on-chip combining in the VNIR can be overcome.

The goal of this topic is to demonstrate a laser source operating in the VNIR and designed for optimum size, weight, and power (SWaP), while also reducing the cost (SWaP-C). The source should be a laser array integrated on the same chip and combined into a single output, which is considered to be the key technical achievement of the effort. The minimum required continuous wave (CW) output power is 1.5 W, and the power should be distributed in at least six spectral lines. More lines are desirable, and increasing the number of integrated lasers represents an acceptable way of scaling to the required power

VERSION 4

output. The source should cover the entire VNIR band, with at least 20% of the total output power appearing in each of the sub-bands: 0.5-0.6 microns, 0.6-0.7 microns, and 0.7-0.85 microns. The output should also be placed at spectral lines corresponding to wavelengths of maximum atmospheric transmission. While the maximum number of discrete laser diodes that can be integrated on a single chip is fundamentally limited by die size and beam-combining losses, nothing about the chosen architecture should preclude further power scaling by external (off-chip) combining of multiple integrated laser arrays. In particular, the combined beam output from the chip should be of high quality, with M2 less than 2.0 and with 1.5 as a goal (note that M2 is defined by ISO Standard 11146 for this effort).

The solution must demonstrate the laser source as a packaged prototype laser module. Of fundamental importance is low SWaP, with a size goal of less than 20 cubic inches for the entire laser module and a weight goal of less than one pound. In this context, the “laser module” comprises the integrated on-chip combined laser array (which is the laser source), the mount (including thermal stack-up), the optics required for transmitting the output beam, and the packaging (including electrical and coolant connectors), but does not include the mounting hardware or power supplies. External optics for shaping the beam are acceptable, so long as they fit within the specified total module volume. Although the prototype module produced during Phase II need not be environmentally hardened, it must be contained within a closed package rather than an open breadboard.

The laser module prototype is intended for laboratory demonstration and limited outdoor range testing. However, for ease of use and in order to inform future system concepts, the laser module will be integrated with a closed-loop cooler, power supplies, and control circuitry to form a system demonstrator prototype. The system demonstrator will accept normal 60 Hz 120 V prime power and employ air cooling (convective or forced). The system demonstrator also need not be environmentally hardened, but should be capable of operation in ambient temperatures ranging from 40 to 90°F. Other than electrical prime power, the demonstrator should be self-contained and no larger than 300 cubic inches, including the laser module. The total weight of the demonstrator is not restricted. While the laser module is an integral part of the demonstrator, it should be removable to accommodate the possibility of substituting different laser modules in the future (for example, modules emitting with different spectral line placement). As a benchmark, the demonstrator prototype should be designed to meet a cost goal of \$10,000 per unit when manufactured in a volume of 1,000. At the conclusion of the effort, the demonstrator unit will be delivered to the Naval Research Laboratory.

PHASE I: Develop a concept for a compact high-power integrated VNIR laser source that meets the objectives stated in the Description. Define the laser source architecture and demonstrate the feasibility of the concept in meeting the parameters of the Description. Feasibility shall be demonstrated by a combination of analysis, modelling, and simulation. The cost estimate for the concept shall be obtained by analyzing the key manufacturing steps and processes, their maturity and availability within the industry, the cost and availability of key components, and by comparison to the manufacture of similar items. The Phase I Option, if exercised, will include the laser source specification, the laser demonstrator system specification, test specifications, interface requirements, and capabilities description necessary to build and evaluate the full system demonstrator prototype in Phase II.

PHASE II: Develop and deliver a prototype compact high-power integrated VNIR laser source based on the results in Phase I. The integrated laser source (within the laser system demonstrator) shall be demonstrated by producing and testing a prototype (or multiple prototypes) in a laboratory environment. Multiple prototypes (or partial prototypes) may be produced as the design process is assumed to be necessarily iterative in nature. However, at the conclusion of Phase II, the final (best performing) prototype laser source, integrated with the system demonstrator, shall be delivered to the Naval Research Laboratory along with complete test data, a final manufacturing analysis, and final production cost estimate.

VERSION 4

PHASE III DUAL USE APPLICATIONS: Assist the Navy in transitioning the technology for Government use. Specific manufacturing steps and processes that require development will be identified. Iterative testing will establish a hardware configuration baseline, produce production level documentation, and transition the laser source into production. Assist the Government in incorporating the integrated laser source into next higher assemblies and deployable systems.

Law enforcement, commercial, and scientific applications include use of VNIR lasers as sources for laser spectroscopy in detection of hazardous materials and chemical substances. The technology should also find application in the telecommunications sector as sources for wavelength multiplexed communications.

REFERENCES:

1. Zhao, Yunsong and Zhu, Lin. "On-Chip Coherent Combining of Angled-Grating Broad-Area Diode Lasers." Optics Express, Vol. 20, Issue 6, 2012, pp. 6375-6384. <https://www.osapublishing.org/oe/fulltext.cfm?uri=oe-20-6-6375&id=229737>.
2. Pauli, M. et al. "Power Scaling and System Improvements to Increase Practicality of QCL-Based Laser Systems." Proceedings of the SPIE 10926, 27 June 2019. <https://doi.org/10.1117/12.2508710>.
3. Chang, Hsu-Hao, et al. "Integrated Hybrid Silicon Triplexer." Optics Express, Vol. 18, Issue 23, 2010, pp. 23891-23899. <https://www.osapublishing.org/oe/fulltext.cfm?uri=oe-18-23-23891&id=206982>.
4. Latkowski, S., et al. "Monolithically Integrated Laser Sources for Applications Beyond Telecommunications." Proceedings of the SPIE, Physics and Simulation of Optoelectronic Devices XXVIII, 11274N, 2 March 2020. https://spie.org/Publications/Proceedings/Paper/10.1117/12.2552784?origin_id=x4325&start_volume_number=11200.

KEYWORDS: VNIR Lasers; Near-Infrared; Laser Source; Semiconductor Lasers; Beam Combining; Laser Diodes.

VERSION 4

N22A-T015 TITLE: Additive Manufacturing of High Performance Copper-Based Components and Materials

OUSD (R&E) MODERNIZATION PRIORITY: General Warfighting Requirements (GWR)

TECHNOLOGY AREA(S): Materials / Processes

OBJECTIVE: Develop additive manufacturing (AM) processes to produce high performance copper-based components and materials.

DESCRIPTION: Additive manufacturing (AM) has matured rapidly over the past decade and is currently a viable manufacturing process in many industries. This is especially true in the production of polymer parts. AM not only allows production of specialized components in small quantities, but it also makes possible the creation of devices and materials that cannot be otherwise produced by traditional means. Additive manufacturing of metals has also matured rapidly; however, the utility of metal AM has not been realized as fully as for polymer processes. This is especially true in the defense electronics and defense systems industries.

To a large extent, AM has been seen as a tool for the production of solid models (rapid prototyping), on-demand manufacturing, and in the fabrication of complete parts where traditional fabrication techniques would require the joining of multiple components. However, the full potential of AM lies in the fabrication of parts and materials that cannot be realized by any other means. This is already being exploited in polymer AM processes where the material constituents can be changed “on the fly” during the fabrication process to achieve gradations in material properties that create specific performance characteristics. For example, the current state of the art for polymer-based materials allows the dielectric constant of a part to be varied throughout the part using advanced additive techniques.

In defense electronics, stringent requirements place unparalleled demands on materials selection and performance, which directly increases cost. Mechanical and especially thermo-mechanical properties of metals used in high performance radio frequency (RF) and laser systems are a primary concern during design and material selection. These metals typically serve as mechanical supports and heat transfer paths for high power electronics. In other applications they serve directly as RF circuit components (such as connectors, transmission lines, waveguides, and antenna elements). Modern vacuum electronics use metal and ceramic construction exclusively, with material purity and performance being of paramount concern.

The Navy has a compelling interest in developing components and materials that increase the overall performance of high-power sensor (radar and electronic warfare) and weapon systems. Specifically, for this topic, this means developing AM processes for copper and copper-based materials and structural elements (at very small scales) that provide performance characteristics exceeding what can be obtained through traditional manufacturing processes. “Copper-based materials” include both copper alloys and metal matrix composites (including hybrid composites) where the primary metal constituent is copper. For structural (three-dimensional vice planar) elements, the interior dimensions of WR-10 waveguide (0.100 X 0.050 inches) serve as the benchmark for the feature size and aspect ratio desired. That is, RF circuit components are assumed to require this level of resolution and cooling channels should achieve these dimensions (or smaller) to be useful.

There are two key aspects to this STTR topic: (1) the demonstration of three-dimensional structures with fine (high aspect ratio) features, tight tolerances and smooth surfaces, and (2) the development of innovative materials. Either may be selected and addressed, both may be addressed separately, or both may be addressed in combination. For the demonstration of three-dimensional structures, a 10X improvement in feature aspect ratio, tolerance, and surface roughness over the current state of the art is

VERSION 4

the goal. The objective is to demonstrate through the production and testing of prototypes the ability of the innovative process (or combination of processes) to deliver parts that cannot be manufactured by traditional (non-AM) means. And while either new structures or new materials may be addressed under this effort, innovative AM processes and techniques that demonstrate multiple benefits and utility for wide application are most desirable.

Of particular interest to the Navy are materials and components for thermal management of high power electronic modules. These may be solid heat spreaders or small cooling structures (base plates) incorporating small channels for liquid cooling. Along these lines, thin oscillating heat pipes (OHPs) are an area that embodies multiple technical challenges of particular interest (for example, feature size, tolerance, finish, and affordability). Typically, these components find their most challenging application in transmit and receive (T/R) modules incorporating high power monolithic microwave integrated circuit (MMIC) amplifiers and in high power laser modules incorporating large numbers of solid-state laser diodes. In these cases, differences in the coefficient of thermal expansion (CTE) between the device being cooled and the module structural elements create significant design challenges. Therefore, materials that show superior heat transfer and CTE matching performance through the gradation of material constituents and properties are of great interest. Likewise, innovative structures or composites that provide built-in strain relief as well as superior thermal performance are also of interest. In either approach, AM solutions that provide comparable performance (to the current state of the art) while reducing overall cost (target of 50%) through the elimination of other components or assembly steps are also desired.

Another particularly challenging application of interest is the fabrication of components for vacuum electron devices (VEDs), especially high frequency (>28 GHz) amplifiers such as traveling wave tubes (TWTs). The metal components used in fabrication of a TWT are, by nature, three dimensional with large aspect ratios, require demanding mechanical tolerances, and exhibit high standards of finish and metallurgical quality. Copper is widely used in all VEDs for its good electrical and thermal conductivity properties and for the vacuum properties copper exhibits when produced in its high purity grade. However, copper is relatively soft, deforms and melts at relatively low temperatures, and can be difficult to machine. Consequently, VED fabrication typically includes the joining of copper to other metals and ceramics through brazing and, to a lesser extent, welding. So, AM processes that produce superior copper parts for VED fabrication are also of great interest. This includes processes that improve mechanical and heat transfer performance, improve the joining of parts, and reduce cost by the elimination of traditional machining steps. Again, this may be done through the development of innovative structures or innovative copper-based materials (or combinations of both).

The Navy seeks to develop an AM capability that benefits the RF and electro-optical electronics industry and not to produce any particular part. The solution is assumed to include the development of new AM hardware, feedstock, tooling, design methodologies, and fabrication steps. It also includes the identification of, development of, refinement of, and application of measurement techniques for use both as in-process checks and for use post-fabrication to assess the efficacy of the new capability. Copper is chosen because of its relevance to the electronics industry and because of the particular challenges it presents to AM. Prototype devices and structures should be selected to demonstrate the innovative AM capability. These prototypes should be “real” components that demonstrate relevance to the electronics industry, not just material samples (“blanks”) for testing. Prototype components and devices should demonstrate utility and performance that cannot be achieved through manufacturing by traditional means. Otherwise, the selection of prototypes is not restricted and the examples cited above are not exhaustive. It should also be noted that the overall solution may include traditional treatment techniques such as annealing, chemical polishing, and hot isostatic pressing. However, solutions that require extensive “clean-up” machining are not considered sufficiently additive in nature and will not be considered. Processes that use traditionally fabricated parts or stock as foundations for further fabrication of AM structures and materials are acceptable.

VERSION 4

PHASE I: Propose a concept for additive manufacturing of high performance copper and copper-based materials that meets the objectives stated in the Description. The concept shall include specific prototypes by which the proposed AM process technology will be demonstrated. These prototypes will subsequently be produced and used (in Phase II) to verify, by testing and analysis, the efficacy of the proposed AM concept. During Phase I, feasibility of the concept shall be demonstrated by a combination of analysis, modelling, simulation, and evaluation of proposed process steps against established manufacturing methods. The Phase I Option, if exercised, will include the initial process specifications, AM equipment requirements, test specifications, and capabilities description to build a prototype additive manufacturing facility in Phase II.

PHASE II: Develop and demonstrate a prototype facility for AM of high performance copper-based components and materials. In this context, “facility” refers to the combination of equipment, tooling, and process steps required to demonstrate the end-to-end additive manufacturing capability provided by the proposer, not the actual physical facility. Demonstration of the AM process (or multiple processes) shall be accomplished by fabrication and evaluation of the prototype components and materials identified during Phase I. Multiple prototype components and samples are expected during execution of this Phase as the process development is assumed to be necessarily iterative in nature. However, at the conclusion of Phase II, at least one example of each proposed prototype component or material sample shall be delivered to the Government with no fewer than five total prototype samples delivered overall. Test data shall also be delivered with each prototype sample delivered.

PHASE III DUAL USE APPLICATIONS: Support the Navy in transitioning the technology for Government use. Identify specific products and material formulations appropriate to the new AM processes and, in conjunction with the broader industry, develop specific production flows and process parameters to either market finished copper-based AM products or transition the technology to produce them in quantity.

The technology resulting from this effort is anticipated to have broad commercial application in the electronics industry as well as niche application to the broader industry for applications such as heat exchangers and thermal management components for electrical power conversion.

REFERENCES:

1. Horn, Timothy J. and Gamzina, Diana. “ASM Handbook, Volume 24, Additive Manufacturing Processes.” ASM International, Cleveland, Ohio, 2020, pp. 388-418.
<https://dl.asminternational.org/handbooks/book/119/chapter-abstract/2350563/Additive-Manufacturing-of-Copper-and-Copper-Alloy>.
2. Jordan, Nicholas M., et al. “Additively Manufactured High Power Microwave Anodes.” IEEE Transactions on Plasma Science, Vol. 44, August 2016, pp. 1258-1264.
<https://ieeexplore.ieee.org/document/7479563>.

KEYWORDS: Copper Alloys; Metal Matrix Composites; Thermal Management; Heat Spreaders; Oscillating Heat Pipes; Vacuum Electron Devices

VERSION 4

N22A-T016 TITLE: DIGITAL ENGINEERING - Data-Driven Hypersonic Turbulence Modeling Toolset

OUSD (R&E) MODERNIZATION PRIORITY: Artificial Intelligence (AI)/Machine Learning (ML);Hypersonics

TECHNOLOGY AREA(S): Air Platforms;Weapons

OBJECTIVE: Formulate, implement, and validate data-driven turbulence models for Reynolds Averaged Navier-Stokes (RANS) closure applicable to hypersonic flows with favorable pressure gradients, adverse pressure gradients, shock wave/turbulent boundary layer interaction (STBLI), and high heat flux.

DESCRIPTION: Hypersonic weapons are exposed to harsh operating environments requiring careful calculation of turbulent boundary layers to accurately estimate heat transfer and design thermal protection systems. Given the wide range of altitudes and velocities hypersonic vehicles operate in, the Navy requires a flexible modeling approach. However, direct numerical simulation data, let alone flight test or even wind tunnel experimental data, is expensive to develop and covers only very specific flight profiles. Faster, cheaper modeling approaches are needed to enable design for entire mission profiles. Modeling approaches, such as RANS equations that are well established for incompressible flow, provide inconsistent results, deviating by more than 50% from data when modeling relevant hypersonic flows, especially for STBLI [Refs 2, 3]. The principal problem lies in the models used to determine Reynolds Shear Stresses and turbulent heat flux required to close the RANS equations; existing methods are inadequate for hypersonic flow.

Over the last decade, improvements have been made in the development of data-driven techniques to close the RANS equations. Application of machine learning (ML) provides a powerful extension to empirical and semi-empirical methods common for developing and tuning closure models. ML allows application of much larger data sets with higher accuracy, removing some of the need for assumptions in traditional closures. These approaches typically use available Direct Numerical Simulations (DNS) or Large Eddy Simulations (LES) data sets to train ML models that can then be used on flows for which no high fidelity, scale-resolved results are available. Wang et al. [Ref 4] have improved on legacy RANS closures in square ducts with varying Reynolds number and flows with massive separation with varying Reynolds number and varying geometry. Wang et al. [Ref 5] extended the technique to hypersonic flat plate turbulent boundary layers and obtained substantial improvements over RANS on Mach 8 flow, even using only Mach 2 DNS results; even better results were obtained from an aggregate of Mach 6 and Mach 2 models. Wang's [Ref 5] results point to the potential applicability of data-driven approaches to improve RANS modeling for more generalized hypersonic flow fields. Not only have these approaches been able to provide more accurate modeling, they also can be used to quantify uncertainty [Ref 1]. Uncertainty quantification is especially important for ML and other empirical approaches, which can experience losses in accuracy away from design conditions.

These data-driven applications are, however, not straightforward. Developing these models requires addressing such problems as defining input and output flow field variables for ML that have physical significance, are normalized, and have Galilean invariance [Ref 6]. Additionally, ML on DNS data cannot be used to simply replace terms in the RANS models, as ill-conditioning of the RANS equations and errors in mean flow quantities will result [Ref 1]. ML approaches are commonly used to predict discrepancies between RANS and DNS data [Refs 1, 4, 5] to train the model to predict the discrepancies between RANS calculations and DNS data throughout the flow field, but how this information is used to improve predictions of quantities of interest (such as heat transfer or separation region location) varies. These discrepancies can be used to adjust existing closure models [Ref 1], adjust model parameters [Ref 10], or to correct Reynolds Stress terms [Refs 4, 5]. Added to this is the general difficulty of ML in

VERSION 4

determining the scope of applicability of results, amplified in studying hypersonic flow by variations in Mach number, Reynolds number, flow geometry, and shock geometry that can substantially change the character of flow.

Data driven approaches offer great potential for improving the speed and accuracy of existing hypersonic turbulence models, but product development must take into account the facts that (1) ML corrections to RANS models apply only to a range of flight profiles and vehicle geometries, (2) we must know when a particular ML model loses accuracy due to a change in flow configuration, and (3) ML models can be developed using a wide range of training sets with different choices as to which ML approach (i.e., random forest, neural network, etc.) and different approaches to using the model data to obtain quantities of interest.

PHASE I: Formulate and assess methodologies to improve RANS turbulence models for hypersonic flows using data driven approaches. Specifically, we are seeking a proof of concept for an add-on compatible with existing CFD codes. Significant improvements in the prediction of heat transfer, skin-friction and pressure in attached and separated hypersonic flows are required. Validation against relevant hypersonic experimental data and DNS will be a key consideration towards successful phase transition. The analysis must show that the proposed methodology improves agreement with existing datasets over a wide range of relevant flow conditions. Develop a Phase II plan.

PHASE II: Expand the capabilities and flow configurations of the add-on developed in Phase I. Emphasis should be placed on expanding the models to a wider range of flow geometries, Mach numbers, Reynolds numbers, wall temperature ratios and flight enthalpies. For instance, add ML models based on different training datasets and a variety of data-driven approaches to provide improved accuracy for different flow regimes. Generation of new DNS training datasets can be performed as needed to eliminate gaps in existing datasets. Inclusion of boundary layer transition effects (i.e., length and shape of the transition region and heat transfer overshoot) are needed to increase the applicability of RANS to flow with laminar, transitional and fully turbulent regions. Any new features should be assessed for accuracy.

PHASE III DUAL USE APPLICATIONS: Automate user choice in specific model and flow parameters. Apply uncertainty estimation methods such as those surveyed in Ref 1 to determine which of the expanded training sets, ML models, and closure methods (i.e., Reynolds Stress estimation, coefficients, closure models) will provide the best result for the particular flow profile under consideration, taking into account factors such as geometry, Mach number, Reynolds number, and target quantities of interest (i.e., separation region location and size, heat transfer, etc.). Provide an automated, flexible means of assessing turbulent boundary layers, especially in STBLI without requiring dedicated knowledge and experienced judgment needed to determine the ideal data and model for different flow problems. As with Phase II, specific details of breadth of flows that automation is applicable to and depth of accuracy and detail available, is left to assessment of market need and available developmental resources.

REFERENCES:

1. Duraisamy, Kathik et al. "Turbulence Modeling in the Age of Data." Annual Review of Fluid Mechanics, vol. 51, 2019, pp. 1-23. <https://arxiv.org/pdf/1804.00183.pdf>.
2. Holden, Michael et al. "Comparisons of Experimental and Computational Results from "Blind" Turbulent Shock Wave Interaction Study Over Cone Flare and Hollow Cylinder Flare Configurations." AIAA Aviation Conference, Atlanta, GA, 2014. https://cubrc.org/iassets/docs/6_Wadhams_AIAA_Atlanta_SWTBI.pdf.
3. Georgiadis, Nicholas J. et al. "Status of Turbulence Modeling for Hypersonic Propulsion Flowpaths., NASA/TM-2012-217277. <https://ntrs.nasa.gov/api/citations/20120008521/downloads/20120008521.pdf?attachment=true>.

VERSION 4

4. Wang, Jian-Xun et al. “A Physics Informed Machine Learning Approach for Reconstructing Reynolds Stress Modeling Discrepancies based on DNS Data.” *Physical Review of Fluids*, March 2017. <https://arxiv.org/pdf/1606.07987.pdf>.
5. Wang, Jian-Xun et al. “Prediction of Reynolds Stress in High Mach Number Turbulent Boundary Layers using Physics Informed Machine Learning.” *Theoretical and Computational Fluid Dynamics*, Vol 33, 2019, pp. 1-29. <https://arxiv.org/abs/1808.07752>.
6. Wu, J.L. et al. “Physics- Informed Machine Learning Approach for Augmenting Turbulence Models—A Comprehensive Approach.” *Physical Review Fluids*, Vol 3, 2018. <https://arxiv.org/pdf/1801.02762.pdf>.
7. Zhang, Chao et al. “Direct Numerical Simulation Database for Supersonic and Hypersonic Turbulent Boundary Layers.” *AIAA Journal*, Vol 56, No. 11, 2018. <https://arc.aiaa.org/doi/pdfplus/10.2514/1.J057296>.
8. Duraismy, Karthik et al. “Augmentation of Turbulence Models Using Field Inversion and Machine Learning.” *AIAA SciTech Forum*, 55th Aerospace Sciences Meeting, Grapevine Texas, Jan 2017. <https://deepblue.lib.umich.edu/bitstream/handle/2027.42/143032/6.2017-0993.pdf?isAllowed=y&sequence=1>.
9. Gnoffo, Peter et al. “Uncertainty Assessments of 2D and Axisymmetric Hypersonic Shock Wave-Turbulent Boundary Layer Interaction Simulations at Compression Corners.” 42nd AIAA Thermophysics Conference, 27-30 June 2011, Honolulu, Hawaii. <https://arc.aiaa.org/doi/pdf/10.2514/6.2011-3142>.
10. Durbin, Paul. “Some Recent Developments in Turbulence Closure Modeling.” *Annual Review of Fluid Mechanics*, Vol. 50, 2018, pp. 77-103. <https://www.annualreviews.org/doi/abs/10.1146/annurev-fluid-122316-045020>.

KEYWORDS: Turbulence modeling; data-driven; machine learning; ML; hypersonics; boundary layers; Reynolds-averaged Navier–Stokes equations; RANS; Direct Numerical Simulations; DNS; Large Eddy Simulations; LES

VERSION 4

N22A-T017 TITLE: DIGITAL ENGINEERING - Rapid Personal Protective Equipment (PPE) Design Exploration

OUSD (R&E) MODERNIZATION PRIORITY: Artificial Intelligence (AI)/Machine Learning (ML);General Warfighting Requirements (GWR)

TECHNOLOGY AREA(S): Biomedical;Human Systems;Materials / Processes

OBJECTIVE: Develop a digital design tool for personal protective equipment (PPE) that allows for rapid exploration of the entire design space.

DESCRIPTION: Developing high-performing, detailed designs of PPE require a thorough examination of conceptual designs and experimental testing. Testing numerous designs is costly and time consuming, both of which contribute to delayed product development and deployment. Moreover, traditional non-biofidelic physical human surrogates limit the translation from testing to the actual response of the warfighter in theater. To facilitate faster and rational design decisions, modeling and simulation utilizing biofidelic human body models can streamline the design process. However, even current state-of-the-art models can still be time consuming to develop, modify, and analyze. New digital technology that allows for rapid design exploration to couple with state-of-the-art models is needed in order to leverage the advantages of computational modeling. PPE design parameters (e.g., fit, form, weight, material) can be extensively probed on digital human models with accurate injury risk analysis prior to the first physical prototype.

PHASE I: Conceive of and clearly articulate a feasible formulation for a digital design tool for PPE using digital engineering principles used by the DoD. A complete plan for the PPE digital design tool should be developed and the methods of creation for this tool should be fully explained. A methodology for a future approach to validation of the PPE design tool should be presented including how the tool would reduce system design costs, how the tool would allow novel designs to be explored, and how the design tool would specify the characteristics of the PPE under development. Develop a Phase II plan.

PHASE II: Build a functional prototype PPE development tool with a Graphical User Interface (GUI) and the required related environment. Integrate the prototype PPE software tool with a human digital twin that is created in the physics-based solvers, LS-Dyna and FEBio finite element software packages. Create a functional system using both the PPE development tool and the human digital twin with two novel PPE designs that demonstrate the ability to estimate injury risk for any given PPE design as well as the characteristics of the PPE itself (e.g., coverage, dimensions, material). Conduct a cost savings analysis to compare the PPE design tool to more traditional design methods for creating novel PPE items to demonstrate the value of the design tool to reduce acquisition costs.

PHASE III DUAL USE APPLICATIONS: Build and deploy a functional PPE design tool at a Navy organization, preferably within the Naval aviation realm. Verify and validate the ability of the PPE design tool to produce protective gear that are functional, achievable with currently available materials and material handling processes, and provide the protection and injury risk reduction as predicted by the design tool during in silico design processes.

Develop a plan for the sustainment and improvement of the design software tool over time so that the tool does not become outdated or irrelevant due to advances in injury risk prediction, human body modeling, personal protective equipment fundamentals; development of new protective materials, system optimization methodologies, application of AI/ML, or technological advances in related technologies and supporting data sets such as constitutive properties of biological tissues and materials used in PPE systems. Address how the PPE design software tool can address the requirements for military and dual-

VERSION 4

use PPE, especially body armor, helmets, sensory system protection (e.g., goggles, wearable noise abatement systems), bomb suits, as well as civilian PPE systems such as hard hats, football helmets, and PPE for manufacturing facilities. Software tool can be formulated to be sustained and improved over time to remain functional. Commercialization must include DoD applications and may include non-DoD applications.

REFERENCES:

1. Zimmerman P.; Gilbert, T. and Salvatore, F. "Digital engineering transformation across the Department of Defense." *The Journal of Defense Modeling and Simulation: Applications, Methodology, Technology*, 16(4), 2017, pp. 325-338.
<https://journals.sagepub.com/doi/abs/10.1177/1548512917747050?journalCode=dmsa>.
2. Olivares, G. and Yadav, V. "Mass transit bus-vehicle compatibility evaluation during frontal and rear collisions." *Proc 20th Int Technical Conf Enhanced Safety of Vehicles*, 2007. Paper number 07-0477. <https://www-esv.nhtsa.dot.gov/Proceedings/20/07-0477-O.pdf>.
3. Bredbenner, T.L.; Eliason, T.D.; Francis, W.L.; McFarland, J.M.; Merkle, A.C. and Nicolella, D.P. "Development and validation of a statistical shape modeling-based finite element model of the cervical spine under low-level multiple direction loading conditions." *Frontiers in Bioengineering and Biotechnology*, 2: 58, 2014.
<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4245926/>.
4. Michalski, A.S.; Amin, S.; Cheung, A.M.; Cody, D.D.; Keyak, J.H.; Lang, T.F.; Nicolella, D.P.; Orwoll, E.S.; Boyd, S.K. and Sibonga, J.D. "Hip load capacity cut-points for Astronaut Skeletal Health NASA Finite Element Strength Task Group Recommendations." *npj | Microgravity*, 2019, 5: 6. <https://www.nature.com/articles/s41526-019-0066-3.pdf>.
5. Olivares, Gerardo. "Integrated Occupant Safety for Urban Air Transport Emergency Landing Applications." 8th Biennial Autonomous VTOL Technical Meeting and 6th Annual Electric VTOL Symposium. Mesa, AZ USA.
https://www.researchgate.net/publication/330764309_Integrated_Occupant_Safety_for_Urban_Air_Transport_Emergency_Landing_Applications (Note: Full text of article available upon request from author.)
6. Goertz, A.; Viano, D. and Yang, K.H. "Effects of Personal Protective Equipment on Seated Occupant Spine Loads in Under-Body Blast: a Finite Element Human Body Modeling Analysis." *Human Factors and Mechanical Engineering for Defense and Safety*, Vol 5, Issue 1, January 6, 2021. <https://www.mysciencework.com/publication/show/effects-personal-protective-equipment-seated-occupant-spine-loads-underbody-blast-finite-element-human-body-modeling-an-1f165f4e?search=1>.

KEYWORDS: digital engineering; personal protective equipment; PPE; body armor design; helmet design; systems engineering; structural analysis; injury risk reduction; human digital twin; risk analysis; verification and validation models; design models; manufacturing

VERSION 4

N22A-T018 TITLE: Enhanced Sensory Perception via Advanced Synthetic Skins

OUSD (R&E) MODERNIZATION PRIORITY: Artificial Intelligence (AI)/Machine Learning (ML);Autonomy;Microelectronics

TECHNOLOGY AREA(S): Electronics;Materials / Processes;Sensors

OBJECTIVE: Develop an innovative, wide-area synthetic skin that utilizes advances in machine perception to enhance the sensory capabilities of the device or system to which the skin is applied and for enhanced investigative capabilities in low-visibility, undersea environments.

DESCRIPTION: A key characteristic of a high-performing synthetic sensory skin is the ability to remain fully operational when stretched, deformed, or used in undersea operations conducted in harsh environments. There are technical risks associated with the implementation of synthetic skins with human-like sensory capability such as manufacturability, resiliency, sensors, and data processing. This STTR topic seeks to develop innovative, wide-area, synthetic sensory skin technologies that address these risks. Solutions should provide high-functioning synthetic sensory skin that augments operations in low-access, low-visibility environments as well as in missions requiring teleoperations of critical systems.

PHASE I: Conduct a proof-of-concept study, culminating in a design package and a demonstrable simulation and/or laboratory experiment, that proves the feasibility of achieving the desired synthetic sensory skin requirements. Produce a detailed report summarizing simulation and/or testing results, a presentation of the initial design, and plans for prototyping the synthetic skin in Phase II.

PHASE II: Finalize design details through Preliminary and Critical Design Reviews, provide a manufacturability analysis, and develop and demonstrate the prototype synthetic skin in a relevant environment.

PHASE III DUAL USE APPLICATIONS: Support the Navy in transitioning the technology to a program of record for operational use. Potential medical applications include telemedicine, where it could enable a medical clinician to replicate the physical contact they have when they evaluate a patient in person, and as a covering for prosthetic limbs. Another commercial application includes using it to enable robots to work more safely around humans.

REFERENCES:

1. Majidi, C. "Soft Robotics: A Perspective—Current Trends and Prospects for the Future." *Soft Robotics*, Vol. 1, Issue 1, 2013. <https://www.liebertpub.com/doi/10.1089/soro.2013.0001>.
2. Technical University of Munich (TUM). "Biologically-Inspired Skin Improves Robots' Sensory Abilities." *Science Daily*, October 10, 2019. <https://www.sciencedaily.com/releases/2019/10/191010125623.htm>.
3. Dahiya, R.; Manjakkal, I.; Burdet, E. and Hayward, V. "Large-Area Soft e-Skin: The Challenges Beyond Sensor Designs." *Proceedings of the IEEE*. Vol. 107, No. 10, October 2019. <https://www.cim.mcgill.ca/~haptic/pub/RD-ET-AL-PIEEE-19.pdf>.

KEYWORDS: artificial intelligence; perception; underwater; robotics; synthetic skin; bio-inspired; materials; microelectronics; sensors

VERSION 4

N22A-T019 TITLE: Enhanced Thermal, Mechanical, and Physical Properties of Ceramic Matrix Composites Through Novel Additives

OUSD (R&E) MODERNIZATION PRIORITY: General Warfighting Requirements (GWR);Hypersonics;Space

TECHNOLOGY AREA(S): Air Platforms;Materials / Processes;Space Platforms

OBJECTIVE: Enhance and optimize oxidation resistance and thermal, mechanical, and physical properties of ceramic matrix composites (CMCs) through computational-directed and validated design and the addition of additive(s) to the CMC.

DESCRIPTION: The service life of ultra-high temperature materials such as CMCs in gas turbine engines or hypersonic applications is dependent on a complex combination of temperature-stress- environment-time conditions. Maximizing thermal transport to avoid local hot spots on leading edges of reusable hypersonic structures and optimizing tensile strength require a thorough understanding of CMC phenomena. Additives such as nanoparticles and micron-sized chopped fibers have been reported to reduce localized mechanically and thermally-induced stresses thereby increasing overall strength and toughness. Informed design will enhance interphase coatings and reduce CMC porosity. Modeling strength and deformation processes of CMCs as a function of CMC structure and additive load will lead to fabrications processes that maximize CMC component strength.

PHASE I: Using Integrated Computational Materials Engineering (ICME) functionalities, establish models to predict the effect of composition on phase stability and key properties in ceramic matrices such as thermomechanical and thermochemical behavior with and without the application of additives as a function of temperature. The ICME effort needs to be combined with experimental approaches to generate requisite information for model validation. Develop a process for applying novel additives to CMC fibers. Evaluate the oxidation resistance and creep resistance of SiC CMC fibers with and without the addition of novel additives as a function of temperature up to 2000oC, if possible. Develop a Phase II plan.

PHASE II: Apply validated models, developed in Phase I, to the synthesis of advanced matrices and coatings, initially as monolithic materials and later in sub-systems and complete EBC/CMC systems. In coordination with an appropriate original equipment manufacturer (OEM), establish and execute a test plan that will provide sufficient data for preliminary assessment of design allowables for critical and relevant design requirements. These requirements will be developed in conjunction with an OEM and ONR. Test samples will be manufactured with different testing geometries (necessitated by uniformity and testing hardware requirements) for determination of thermal and mechanical property data, including: density, hardness, thermal conductivity, thermal expansion, tensile strength, modulus, creep, and creep rupture, and vibrational and dynamic fatigue.

Test conditions shall include controlled stress, temperature, and time under environmental conditions, including simulated turbine engine by-products of combustion gases with and without sodium sulfate and water present. By the end of the Phase II, ensure that data will be available to initiate constituent modeling of modified CMCs with lifetime predictions of oxidation resistance and thermal-mechanical-creep performance up to 100 hours. Also ensure that thermal-mechanical-creep tests will reach up to 1000 hours at 2000°C or more.

PHASE III DUAL USE APPLICATIONS: Adoption of models/optimized matrix by an OEM for further maturation to manufacture robust self-healing matrix CMC components that can operate in complex environments with less maintenance, lower overall life cycle cost, and improved operational capabilities.

VERSION 4

Coordinate with an engine OEM on work toward further maturation of the knowledge and/or process to fabricate CMC engine components for military and commercial platforms or show how the CMCs with additives can perform at temperature exceeding 2000°C.

REFERENCES:

1. DeCarlo, J.A. and van Roode, M. "Ceramic Composite Development for Gas Turbines Engine Hot Section Components." ASME Turbo Expo 2006, Power for Land, Sea and Air, May 8-11, 2006, Barcelona, Spain. Paper GT2006-90151.
<https://asmedigitalcollection.asme.org/GT/proceedings-abstract/GT2006/42371/221/314649>.
2. Padture, N.P. "Environmental Degradation of High-Temperature Protective Coatings for Ceramic Matrix Composites in Gas Turbine Engines." Nature: npj Materials Degradation, v. 3, p.11, 2019.
<https://www.nature.com/articles/s41529-019-0075-4>.
3. "US Hypersonic Initiatives Require Accelerated Efforts of the Materials Research Community." MRS Bulletin, Vol. 46, March 2021. <https://link.springer.com/content/pdf/10.1557/s43577-021-00050-2.pdf>.
4. Lauten, F.S. and Schulberg, M.T. "Composite Materials for Leading Edges of Enhanced Common Aero Vehicles and Hypersonic Cruise Vehicles." Physical Sciences Inc., 2006.
5. Evans, A.G.; Zok, F.W.; McMeeking, R.M. and Du, Z.Z. "Models of high temperature, environmentally assisted embrittlement in ceramic-matrix composites." Journal of the American Ceramic Society, Vol. 79, Issue 9, September 1996, pp. 2345-2352.
<https://ceramics.onlinelibrary.wiley.com/doi/10.1111/j.1151-2916.1996.tb08982.x>.

KEYWORDS: Ceramic Matrix Composite; CMC; gas turbines; hypersonics; nanoparticles; ultra-high temperatures; oxidation resistance; metal carbines

VERSION 4

N22A-T020 TITLE: Lidar-like 3D Imaging System for Accurate Scene Understanding

OUSD (R&E) MODERNIZATION PRIORITY: Artificial Intelligence (AI)/Machine Learning (ML);Autonomy

TECHNOLOGY AREA(S): Information Systems;Sensors

OBJECTIVE: Develop inexpensive Lidar-like 3D imaging sensors that have high depth and lateral resolution, have a large field-of view for reliable object detection, respond in real time, and work at medium to long ranges in indoor and outdoor environments.

DESCRIPTION: 3D scene understanding (i.e., 3D scene segmentation and parsing, depth estimation, object detection and recognition) are essential components in a vision system. 3D sensors similar to Microsoft Kinect are inexpensive and high resolution but have limited range outdoors, thus not suited for many robotics applications. Lidars have long range and high depth accuracy, but are very expensive; for example, those used in self-driving cars are typically several times more expensive than other car components. Another drawback of current Lidars is their small “vertical” field-of-view, which results in limited vertical resolution and accuracy in object detection because Lidars (even the more expensive ones) have at most 64 scan lines, which could fail to detect small objects even at medium range distances.

The goal of this STTR topic is to develop inexpensive, high-resolution, high-accuracy 3D imaging sensors for wide use on a variety of large and small ground and aerial robotic platforms that can work in dynamic environments under different conditions. ONR expects recent promising advances along a number of directions including machine learning-based algorithms for improved depth estimation with stereo cameras [Refs 2, 5], active illumination technologies [Ref 1], and optimal time-of-flight coding [Ref 3], etc., open new approaches to building hybrid systems that combine optical cameras and laser ranging for developing such 3D imaging sensors. Combining these advances (ML-based stereo imaging, utilizing active illumination for 3D imaging, and novel time-of-flight coding for improved range estimation) requires innovative approaches.

PHASE I: Design the system architecture including sensors and computing hardware, and processing and inference algorithms for building inexpensive, high-resolution, accurate, 3D imaging sensors. Since these sensors are intended for use on various UGVs and UAVs deployed in dynamic and cluttered environments, the design should consider tradeoff estimates among size, weight, and power (SWAP), as well as resolution, detection accuracy, operating range, frame rate, and cost. Develop a breadboard version to demonstrate the feasibility of the design. Develop a Phase II plan.

PHASE II: Perform experiments in a variety of situations and refine the system. Goals for Phase II are: (a) the system should have a field-of-view and resolution comparable to optical cameras; (b) Demonstrate the system’s capability for human detection. Normal vision can detect humans up to a distance of about 300m in daylight. At nighttime, typical headlights illuminate the road up to a distance of about 60m [Ref 4]. The minimum detection range should be the aforementioned distances in daylight and nighttime. (c) Develop a compact prototype imaging system that is small, lightweight, and low power, suitable for portability by personnel and small autonomous platforms (UxVs).

PHASE III DUAL USE APPLICATIONS: Perform additional experiments in a variety of situations and further refine the system for transition and commercialization. Ensure that the real-time imaging system is operable in real-world dynamic environments, thus extending the imaging to handle real-time acquisition, that is, at least 30 fps. This technology could be used in the commercial sector for self-driving cars, and in surveillance and navigation on any land or air vehicle.

VERSION 4

REFERENCES:

1. Achar, Supreeth et al. "Epipolar Time-of-Flight Imaging." ACM Transactions on Graphics, Vol. 36, No. 4, Article 37, July 2017. <https://dl.acm.org/doi/pdf/10.1145/3072959.3073686>.
2. Garg, D. et al. "Wasserstein Distances for Stereo Disparity Estimation." 34th Conference on Neural Information Processing Systems (NeurIPS 2020), Vancouver, Canada. <https://arxiv.org/pdf/2007.03085.pdf>.
3. Gupta, M. et al. "What are Optimal Coding Functions for Time-of-Flight Imaging?" ACM Transactions on Graphics, Vol. 37, No. 2, Article 13, February 2018. <https://dl.acm.org/doi/pdf/10.1145/3152155>.
4. Farber, Gene. "Seeing with Headlamps." NHTSA Workshop on Headlamp Safety Metrics, Washington, DC, July 13, 2004. <https://pdf4pro.com/view/seeing-with-headlights-4b1377.html>.
5. Wang, Yan et al. "Pseudo-LiDAR From Visual Depth Estimation: Bridging the Gap in 3D Object Detection for Autonomous Driving." CVPR 2019. <https://arxiv.org/pdf/1812.07179.pdf>.

KEYWORDS: Lidar-like 3D imaging sensor; hybrid imaging; high-resolution sensor with large field of vision; FOV; outdoor imaging; indoor imaging

VERSION 4

N22A-T021 TITLE: Affordable Stabilized Directional Antennas for Small Platforms

OUSD (R&E) MODERNIZATION PRIORITY: Networked C3

TECHNOLOGY AREA(S): Battlespace Environments;Electronics;Ground / Sea Vehicles

OBJECTIVE: Develop a low-cost inertially stabilized mechanism for motion compensation on antenna beam pointing and tracking aboard buoys and small crafts subject to winds, waves, and vehicle motion. Capability goals include low Size/Weight/Power (SWAP), high fault tolerance, and ability for customization and integration with representative antennas.

DESCRIPTION: Current small radio implementations for sensor exfil, telemetry, and data-on-the move lack the performance capabilities to connect small unmanned platforms to communication gateways separated by extended communication link ranges. Recent advances in antenna structures have proven significant increases in gain performance, thereby enabling link closure at farther ranges without increased transmit power. However, advanced inertial measurement electronics and algorithms are needed that can provide fine beam pointing, acquisition, tracking, stabilization (PATS) accuracy required in various environments. It is paramount this innovative solution has low cost, low size/weight/power (SWAP), high fault tolerance, ability for customization, and easy integration into different antenna configurations.

PHASE I: System engineering and trade study for phased array antenna motion-compensating electronics that consists of (i) industrial-grade low-cost commercial off-the-shelf (COTS) IMU/GPS, and (ii) signal processing of incoming IMU data to provide RF beam steering corrections at a rate 100 Hz or higher. Develop varied designs for acquisition, beam pointing and tracking accuracy and performance as a function of electronics/sensor cost, power consumption and size, taking into consideration the requirements for antenna beam width and PATS loss. Develop a case study with detailed design and architecture for integrating the beam correction to a representative phased array antenna up to sea state 4, or for land-based vehicle, on the move. Modeling and simulation results that captures and visualize real-time environmental dynamics and perturbations and their impact on maintaining the RF link stability is highly desirable. Propose solutions for identified gaps and performance improvements. Develop Phase II plans.

Produce knowledge-based deliverables: (1) technical trades and systems engineering addressing cost-size-weight-power and beam PATS loss; (2) architectural designs of stabilized antenna with integrated pointing/tracking in a few frequency bands of interest; and (3) down select prototype design to targeted small radio and antenna systems offering highest value-benefit for Naval stakeholders.

PHASE II: Develop working experimental prototypes based on initial architectural designs delivered in Phase I. Demonstrate the capabilities of developed prototypes in a relevant lab environment up to TRL 4/5. Continue additional integration and tests activities to elevate and achieve TRL 6 during the option Phase, if exercised.

Knowledge-based deliverables: Finalized targeted prototype design.

Hardware & Software deliverables: Prototype system(s) capable of being lab tested up to TRL 4/5. Over-the air limited range test desirable.

Metrics: Objective Size (< 10 cu. in.), weight (< 8 oz), and power (< 1 W); Low cost; Good Pitch/roll/heading accuracy at refresh rate up to 100 Hz; PATS loss < 3 dB for data link at maximum range

VERSION 4

The Phase II Option, if exercised, will include the following deliverables and metrics: Integrated system(s) with local at-sea TRL 6 demonstrations of range and stabilization performance.

PHASE III DUAL USE APPLICATIONS: Develop and refine the final design based on Phase II. Include varied stress testing (extended temperature range, vibration, etc.). Demonstrate autonomous communication capabilities at extended ranges over various sea state environments.

Deliverables: Fully integrated systems on which to conduct rigorous testing with variable beam widths for robust autonomy, stabilization up to sea state 4 and on-the-move platforms, including SATCOM applications.

Private sector commercial potential includes autonomous observation systems, remote monitoring, ocean Internet-of-Things (IOT), and oil and gas exploration.

REFERENCES:

1. Smith, I.S.; Chaffer, E.A. and Walker, C. "Recent Developments in a Large Inflatable Antenna." IEEE Aerospace Conference, 3-10 March 2018, Big Sky, MT. <https://ieeexplore.ieee.org/document/8396633>.
2. Ganti, S.R. and Kim, Y. "Design of Low-Cost On-Board Auto-tracking Antenna for Small UAS." 12th Intl Conference on Information Technology – New Generations, 13-15 April 2015, Las Vegas, NV. <https://ieeexplore.ieee.org/document/7113485>.
3. Hoflinger, F. et.al. "A Wireless Micro Inertial measurement Unit (IMU)." 2012 IEEE International Instrumentation and Measurement Technology Conference, Vol. 62, No.9, May 2012. <https://ieeexplore.ieee.org/document/6229271>.

KEYWORDS: Phased array beam stabilization; Inflatable Antenna; Autonomous Communications

VERSION 4

N22A-T022 TITLE: High Resolution Underwater Optical Ranging

OUSD (R&E) MODERNIZATION PRIORITY: Artificial Intelligence (AI)/Machine Learning (ML);General Warfighting Requirements (GWR)

TECHNOLOGY AREA(S): Sensors;Weapons

OBJECTIVE: Develop techniques to enable high resolution optical ranging in underwater environments that rely on the encoding and decoding of the optical phase and/or the temporal signature of a blue-green laser source while providing accurate range measurements of underwater objects.

DESCRIPTION: Laser-based techniques offer the potential of providing range measurements with high speed and accuracy. When such techniques are used in the underwater environment, they must overcome the challenges of optical absorption and scattering in water. Blue-green wavelengths minimize absorption, but scattering distributes the optical signal in both time and space and reduces range accuracy. Techniques which reduce the contribution of scattered light to the range measurement can enhance optical ranging in challenging underwater environments. The challenge is to develop solutions that provide accurate range measurements (less than 5cm error) with processing speeds that are compatible with a moving underwater platform. Current techniques use time-encoded optical waveforms and subsequent time-resolved detection to discriminate between scattered and unscattered light. Such techniques involve hardware that is not compatible with small platforms and/or have insufficient dynamic range to operate in challenging underwater environments.

PHASE I: Provide model and/or low fidelity proof of concept results for a proposed optical ranging solution. The results should demonstrate how the proposed approach improves optical ranging in underwater environments. Develop a Phase II plan.

PHASE II: Develop a ruggedized hardware prototype that can be operated in relevant laboratory and/or in-situ environments. The prototype should fit within a 10 to 30 inch diameter cylindrical underwater vehicle, and there should be a path to meet the size, weight, and power requirements of a small unmanned underwater platform. Results from the prototype testing should demonstrate improved optical ranging in challenging underwater environments.

PHASE III DUAL USE APPLICATIONS: Work with the Government to transition the prototype hardware to a specific platform meeting that platform's size, weight, and power limitations. Dual use opportunities include unmanned underwater vehicle (UUV) surveying (pipeline inspection) and automotive light detection and ranging (LIDAR).

REFERENCES:

1. Lee, R.W.; Laux, A. and Mullen, L.J. "Hybrid technique for enhanced optical ranging in turbid water environments." Optical Engineering, Vol. 53, No. 5, 2014.
<https://www.spiedigitallibrary.org/journals/optical-engineering/volume-53/issue-5/051404/Hybrid-technique-for-enhanced-optical-ranging-in-turbid-water-environments/10.1117/1.OE.53.5.051404.short?SSO=1>.
2. Jantzi, A.; Jemison, W.; Laux, A.; Mullen, L. and Cochcenour, B. "Enhanced underwater ranging using an optical vortex." Optics Express, vol. 26, no. 3, Feb 5, 2018, pp. 2668-2674.
<https://pubmed.ncbi.nlm.nih.gov/29401804/>.

KEYWORDS: laser ranging; underwater ranging; scattering; optical vortex; turbid; time of flight; LIDAR; undersea weapon; mine detection, mine countermeasure; underwater sensor

VERSION 4

N22A-T023 TITLE: Aquatic Soft Robotic STEM Education Kit

OUSD (R&E) MODERNIZATION PRIORITY: Biotechnology;General Warfighting Requirements (GWR)

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

OBJECTIVE: Develop next-generation STEM Education aquatic robotics kits that employ soft, flexible, and waterproof materials and designs that will become widely accessible to students at various education levels (grades K-12); and support the workforce demands of a technically savvy and innovative current Naval enterprise.

DESCRIPTION: Recent research has shown that students are most challenged to use critical thinking skills when tasked to build around a specific application with specific design criteria [Ref 1]. Therefore, this STTR topic seeks the development of a STEM education toolkit that addresses a specific Naval application (aquatic soft robots) relevant for building the critical skills for future Naval technologies. Building aquatic robots from flexible materials requires a multidisciplinary skill set centered on math, physics, biology, and materials design, all which are valuable to nurture the expertise of the future Naval workforce [Ref 2]. The principles that would be achieved through this aquatic soft robotics toolset would modernize current robotic programs and offer students new and innovative skill sets (manufacturing, material science, mechanical, design and human-robot cooperation) by advancing the state of the art. The toolset should serve educational purposes as well as provide competition and engagement opportunities for building an evolving and growing community.

PHASE I: Demonstrate feasibility through scientifically sound design of a robotic kit that is built using flexible materials that are waterproof. Focus should be on physical concepts such as forces, motion, and friction; and robotics concepts such as actuation, pneumatics and controls; and how all of these can relate to biology. Attention must be paid to the educational instructions, guides, and design in addition to the robotic design. The kit should be adaptable for lesson plans, workshops, home, and school use. Consider educational value through thoughtful design and application of educational principles for each age group. Develop a Phase II plan.

PHASE II: Develop, demonstrate and validate the underwater soft robot prototype educational kit based on the Phase I design concept. Test and evaluate the prototype using meaningful metrics with the appropriate target student populations (as cited in the Description). Develop educational instructions and guides. Ensure that the kit is adaptable for lesson plans, workshops, and home and in-school use. Feasibility of the educational value should be considered through thoughtful design and application of educational principles for each age group.

PHASE III DUAL USE APPLICATIONS: Transition prototype to a partner in the educational sector.

REFERENCES:

1. Holland, D.P.; Walsh, C. and Bennett, G.J. "An assessment of student needs in project-based mechanical design courses." 2013 ASEE Annual Conference & Exposition, Atlanta, Georgia. Paper #7038. https://biodesign.seas.harvard.edu/files/biodesignlab/files/2013_-_holland_-_an_assessment_of_student_needs_in_project-based_mechanical_design_courses.pdf.
2. Calabria, M.F. "Move Like a Shark, Vanish Like a Squid: The Navy Must Invest in Biomimetics to Sustain Dominance on the High Seas." Proceedings USNI, Vol. 147/7/1,421. <https://www.usni.org/magazines/proceedings/2021/july/move-shark-vanish-squid>.

VERSION 4

KEYWORDS: Science Technology Engineering Mathematics Education; STEM; Robotics; Soft materials; Aquatic; Biomimetic; Bioinspired

VERSION 4

N22A-T024 TITLE: Marine Atmospheric Boundary Layer Profiles via Satellite-based Remote Sensing Data Fusion

OUSD (R&E) MODERNIZATION PRIORITY: Artificial Intelligence (AI)/Machine Learning (ML);Space

TECHNOLOGY AREA(S): Battlespace Environments;Information Systems

OBJECTIVE: Develop novel software algorithms to characterize vertical thermodynamic profiles in the lowest 2-3 km of the atmosphere, leveraging satellite-based environmental monitoring (SBEM) data that combines information from at least 2 of the following observing methods: optical, infrared, microwave, radio occultation.

DESCRIPTION: While characterization of the marine atmospheric boundary layer (MABL) environment is fundamental for Naval operations (e.g., directed energy, C4ISR, and communication applications), there is a lack of sufficient data in areas of interest to analyze and predict tactical scale environmental conditions. Current satellite data methods to measure MABL thermodynamics have limitations based on physical observing characteristics, such as horizontal resolution, vertical resolution, refractivity, or temporal refresh. With the proliferation of broader environmental data availability and smallsat platforms, there exists the potential to improve vertical profiles of temperature, water vapor, and/or refractivity in the boundary layer by combining data from two or more observed mediums. Innovation is sought to develop the theory, algorithm, and software to demonstrate, verify, and validate such a satellite data fusion technique. This development will result in valuable knowledge and technology advances beyond DoD specific applications for the entire meteorological analysis and forecasting community.

PHASE I: Determine and demonstrate the technical capability to leverage at least two different environmental satellite remote sensing observation types (including, but not exclusive to, optical channels, infrared channels, microwave imagers, microwave sounders, radio occultation, synthetic aperture radar, etc.) to add value to current single source atmospheric profiling techniques. Identify those factors that will contribute to enhanced understanding of the MABL compared to conventional methods using historical meteorological data from available defense, civil, research, international partner, and/or commercial data streams. Develop a final summary report, including literature review and overall conclusions/recommendations, to be presented at the end of this Phase. Develop a Phase II plan.

PHASE II: Expand technical development and validation of a robust prototype system for retrieval of MABL thermodynamics in a variety of maritime environments. Given feeds of meteorological satellite information, the algorithm should produce near-real time estimates of temperature, water vapor, refractivity at a higher spatial resolution than conventional satellite retrievals, on the order of 250 m vertical and 10 km horizontal. This prototype software should be capable of interoperating alongside conventional satellite algorithms in a similar computing environment, including both a stand-alone server for single algorithmic demonstration and high performance computing cluster for parallelization of near-real time satellite feeds. Demonstration during a government meteorological field event will be coordinated to provide additional verification and validation opportunities. Characterization of data quality and uncertainty will also be necessary to support potential for data assimilation into numerical modeling systems. It is anticipated that the prototype software will be expanded, or in a position to be expanded, to other satellite platforms and/or sensing methods at the conclusion of Phase II efforts, such demonstration/research sensors being demonstrated in near-realtime by NASA. Delivery of a prototype software package and final verification report is expected at the end of this Phase.

PHASE III DUAL USE APPLICATIONS: This development will result in valuable knowledge and technology advances for the entire meteorological analysis and forecasting community. Naval

VERSION 4

applications will immediately benefit from a significant increase in environmental data and prediction availability/quality where the Navy operates. Other civil and commercial applications will benefit from enhanced data streams for broad blue-water maritime applications, improved predictability in numerical weather prediction, and increased cross-over between civil and commercial satellite remote sensing activities. Specifically, environmental characterization and prediction efforts by NOAA will be improved by augmenting meteorological analysis and data assimilation with new observations. Commercial meteorological entities will be able to add value with targeted local enhancement to atmospheric characterization and forecasting by leveraging such data and techniques. This effort has the potential to fill a data gap in all aspects of meteorological analysis as well as provide a proof of concept for additional data fusion opportunities.

REFERENCES:

1. Healy, S.B. and Eyre, J.R. "Retrieving temperature, water vapour and surface pressure information from refractive-index profiles derived by radio occultation: A simulation study." Quarterly Journal of the Royal Meteorological Society, Vol. 126, Issue 566, pp. 1661-1683. <https://doi.org/10.1002/qj.49712656606>.
2. Blackwell, W.J.; Leslie, R. Vincent; Pieper, Michael L. and Samra, Jenna E. "All-weather hyperspectral atmospheric sounding." Lincoln Laboratory Journal, Vol. 18, No. 2, 2010, pp. 28-46. https://www.ll.mit.edu/sites/default/files/page/doc/2018-05/18_2_2_Blackwell.pdf.
3. Lindsey, Daniel T.; Grasso, Louie; Dostalek, John F. and Kerkmann, Jochen. "Use of the GOES-R Split-Window Difference to Diagnose Deepening Low-Level Water Vapor." Journal of Applied Meteorology and Climatology 53, 8, 2014. https://journals.ametsoc.org/view/journals/apme/53/8/jamc-d-14-0010.1.xml?tab_body=pdf.
4. Sun, B.; Reale, A.; Tilley, F.H.; Pettey, M.E.; Nalli, N.R. and Barnet, C.D. "Assessment of NUCAPS S-NPP CrIS/ATMS Sounding Products Using Reference and Conventional Radiosonde Observations." IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, vol. 10, no. 6, June 2017, pp. 2499-2509. doi: 10.1109/JSTARS.2017.2670504.

KEYWORDS: Meteorology; Boundary Layer; Sounding; Profile; Satellite; Remote Sensing; Algorithm; Temperature; Water Vapor; Refractivity

VERSION 4

N22A-T025 TITLE: Enhanced Long-Range Maritime Vessel Classification

OUSD (R&E) MODERNIZATION PRIORITY: General Warfighting Requirements (GWR)

TECHNOLOGY AREA(S): Battlespace Environments;Electronics;Sensors

OBJECTIVE: Develop techniques to exploit ship structural vibrations appearing as micro-Doppler signatures in remote Inverse Synthetic Aperture Radar (ISAR) imagery for the purposes of improved vessel classification.

DESCRIPTION: Significant advancements have been made in the automated classification of ships at long ranges using feature extraction from ISAR imagery. The most capable of these seek to classify a particular ship to the fine naval class level. While physical dimensions of major structural elements of the ship provide the primary classification clues, other micro-Doppler based signatures such as those associated with rotating antennas can provide important additional information to support separation among similar ship classes [Ref 1]. This STTR topic seeks to expand the scope of signatures further. Ship structural vibrations may be another important signature to improve overall classification performance. The sources of structural vibrations are generally understood; however whether they are reliably exploitable for classification clues is unanswered.

Multiple authors have shown that radar-sensed micro-Doppler can be used to remotely monitor the vibration of buildings and bridges [Refs 2, 3]. The vibrations generated by an automobile or truck engine has shown to be detectable by radar micro-Doppler signals returned from the surface of the vehicle [Ref 4]. In principle, ship hull and superstructure vibrations primarily driven by propulsion systems should be similarly detectable. Essential to such a technique is the ability to sense the small-scale vibrations of the vessels while they are in motion [Ref 5]. The exploitation of the vessel hull and superstructure vibrations remotely using legacy Navy airborne maritime surveillance radar systems is desired. In addition to single channel monostatic operation, consideration should be given to interferometric and multi-static techniques. If the vibrations are exploitable at long range by these radar systems, they may provide a hull class specific classification feature that in combination with other features will improve overall classification performance. The signatures may also provide information comparable to a fingerprint if it is found that the spectral characteristics are hull specific.

PHASE I: Utilizing open-source ship hull and superstructure vibration measurements such as those described in [Ref 6] or simulated data, analyze the feasibility of remote micro-Doppler sensing by x-band maritime surveillance radar systems. Single channel monostatic, multi-channel interferometric, and multi-static operation should be considered. An initial assessment of signal processing approaches should be completed. Develop a Phase II plan.

PHASE II: Develop and demonstrate a ship vibration micro-Doppler exploitation mode using collected field data supplied by the Navy sponsor. Assess the performance as a function of range, dwell time, and illumination geometry. Develop mode design and tactical utilization recommendations for radar systems identified by the Navy sponsor.

PHASE III DUAL USE APPLICATIONS: Complete development, perform final testing, and integrate and transition the final solution to naval airborne radar systems either through the radar system OEM or through third party radar mode developers. The technology developed from this STTR topic is applicable to Coast Guard Missions.

REFERENCES:

VERSION 4

1. Chen, V.C. et al. "Analysis of micro-Doppler signatures." IEE Proceedings-Radar Sonar Navigation, Vol. 150, No. 4, August 2003. <http://www.geo.uzh.ch/microsite/rsi-documents/research/SARlab/GMTILiterature/Ver09/PDF/CLHW03.pdf>.
2. Luzi, G. et al. "Radar Interferometry for Monitoring the Vibration Characteristics of Buildings and Civil Structures: Recent Case Studies in Spain." Centre Tecnològic de Telecomunicacions de Catalunya (CTTC/CERCA), Geomatics Division, Avinguda Gauss, 7, E-08860 Castelldefels (Barcelona), Spain. <https://www.mdpi.com/1424-8220/17/4/669/htm>.
3. Luzi, G. et al. "The Interferometric Use of Radar Sensors for the Urban Monitoring of Structural Vibrations and Surface Displacements." IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, Vol. 9, Issue 8, August 2016. <https://ieeexplore.ieee.org/document/7493683>.
4. Chen, V.C. et al. "Micro-Doppler Effect in Radar: Phenomenon, Model, and Simulation Study." IEEE Transactions on Aerospace and Electronic Systems, Vol. 42, No. 1, January 2006. <http://www.geo.uzh.ch/microsite/rsi-documents/research/SARlab/GMTILiterature/Ver09/PDF/CLHW06.pdf>.
5. Rodenbeck, C. et al. "Vibrometry and Sound Reproduction of Acoustic Sources on Moving Platforms Using Millimeter Wave Pulse-Doppler Radar." IEEE Access (Volume 8), 04 February 2020, pp. 27676-27686. <https://ieeexplore.ieee.org/document/8981984>.
6. Weintz, Brett. "Ship vibration." Brabon Engineering Services, 15 June 2021. <https://brabon.org/tech-notes/ship-vibration/>.

KEYWORDS: Inverse Synthetic Aperture Radar; ISAR; Synthetic Aperture Radar; SAR; ship classification; hull and superstructure vibration; radar

VERSION 4

N22A-T026 TITLE: Low-Cost, Low-Power Vibration Monitoring and Novelty Detection

OUSD (R&E) MODERNIZATION PRIORITY: Artificial Intelligence (AI)/Machine Learning (ML);Autonomy;Microelectronics

TECHNOLOGY AREA(S): Electronics;Ground / Sea Vehicles;Materials / Processes

OBJECTIVE: Develop a device to bring the benefits of machine health and usage monitoring to a broad spectrum of Navy and Marine Corps assets, especially those of lower value that cannot afford full-up Health, Usage, and Monitoring System (HUMS) systems by developing powerful, inexpensive processing hardware at a target price of less than \$100.00 per node.

DESCRIPTION: Lower cost USN/USMC platforms (especially land systems) cannot afford conventional HUMS sensors/processors typically priced at over \$1,000.00 per node. Direct sensing of relevant features and the extraction of "actionable" information may be accomplished by purpose-built signal processing hardware. On-chip integration of neural networks (trained offline) holds the promise for self-contained smart sensors that are both extremely powerful and affordable for all platforms. This capability is vital for those platforms deployed and operating at (or beyond) the tactical edge. Very high risk with extremely high payoff is possible if successful. The envisioned device (or family of devices) is expected to be self-contained in a rugged package able to be permanently installed on vehicle components.

This STTR topic seeks innovation in the development of onboard analytics (e.g., neural networks) that operate at the component level and are able to detect and identify anomalous signatures. State of the art is to attach sensors to the component and wire them to conventional signal conditioning hardware in data acquisition components. Digital Signal Processing (DSP) and other computations are done to convert the raw sensor values into information on centralized processors. Some sensors are directly connected to serial buses on the platform with analog-to-digital (A/D) inside the sensor package. The intent is to push the processing into the sensor package, leveraging integration of neural networks and other Artificial Intelligence/Machine Learning (AI/ML) tools at the chip scale to combine the data acquisition and health determination into a single, low-cost device.

PHASE I: Define and develop a concept for a compact device able to monitor, detect, and identify symptoms of failure on typical rotating mechanical equipment. Vibration, temperature, and electrical current signature are typical measurands of interest. The device should be inobtrusive in size and rugged to the ground vehicle's under-hood environment. Approximately 1 cubic inch volume and less than \$100 unit cost. The intent is for the device to be self-contained conducting measurement, analysis, and communications within the package. Ideally it should be environmentally powered or contain energy storage capable of design operation for 1 to 3 years. It should support wired (e.g., CAN bus) or wireless (e.g., IEEE 1451) communications. Perform modeling and simulation to provide an initial assessment of the concept and exercise alternatives. Develop a Phase II plan.

PHASE II: Develop a Phase II prototype for evaluation based on the results of Phase I. The prototype will be evaluated to determine its capability to meet the performance goals defined in the Phase II Statement of Work (SOW) and the Naval need for detection and diagnosis of typical faults in military ground vehicles. In production, the device will be a part of an integrated system of similar devices monitoring different symptoms of faults on a single machine, other similar devices on other machines, and additional control system parametric data captured from existing onboard buses or traditional sensors. The intent is to detect early stage faults at a component level and merge the information to understand the impact of the faults on the mission capability of the platform. Conduct further evaluation of the feasibility of the prototype to evolve into a hardened device capable of surviving in the target environment, meeting

VERSION 4

required cost targets, and performing the necessary analytics. The device should support other third party analytics as well as provide native analytic capability. A family of devices with different processing, memory, and sensing capacity for different applications is anticipated. Testing will be performed on laboratory equipment at the proposer's facility to demonstrate performance. Cybersecurity is a key attribute; “cyber-invisible” is the goal. Formal approval is not to be sought during Phase II, but the design must consider the cyber environment from the outset and incorporate the ability to be properly secured when produced.

PHASE III DUAL USE APPLICATIONS: The technology developed in this effort is intended to comprise a part of an onboard, health monitoring and processing system providing Autonomic Readiness Management (ARM) applicable to all types of naval vehicles. The ARV acquisition program is an ideal target for a rapid maturation and integration into the production process. The FFG-62 Mission Readiness Support System (MRSS) is another acquisition program with need for CBM+ and ARM to which this device could apply.

Commercial uses of the device are everywhere. Interest in condition monitoring for all classes of vehicles is high and lack of an affordable implementation has limited the deployment of the capability. The device developed here is an inherent member of the Internet of Things (IoT) and could be adapted to a variety of applications beyond condition monitoring for vehicles. The fundamental capability to measure, monitor, detect, and project are capabilities that have broad applications across the IoT.

Specific commercial industries/markets that could use and benefit from the technology include: commercial trucking, heavy construction equipment, manufacturing, aircraft and related equipment, commercial maritime, and infrastructure monitoring (e.g., bridges, locks, dams).

REFERENCES:

1. Liobe, J.; Fiscella, M.; Moule, E.; Balon, M.; Bocko, M. and Ignjatovic, Z. “DS Sentry: an acquisition ASIC for smart, micro-power sensing applications.” Proceedings Detection and Sensing of Mines, Explosive Objects, and Obscured Targets XVI, Vol. 8017, 2011, p. 80170H. <https://www.spiedigitallibrary.org/conference-proceedings-of-spie/8017/80170H/DS-Sentry--an-acquisition-ASIC-for-smart-micro-power/10.1117/12.884253.short?SSO=1>.
2. Liobe, J.; Ignjatovic, Z. and Bocko, M. “Ultra-low overhead signal acquisition circuit for capacitive and piezoelectric sensors.” 2008 51st Midwest Symposium on Circuits and Systems, August 2008, pp. 33-36. <https://ieeexplore.ieee.org/document/4616729>.
3. Japkowicz, N.; Myers, C. and Gluck, M. "A novelty detection approach to classification." IJCAI'95: Proceedings of the 14th International Joint Conference on Artificial Intelligence, Volume 1, August 1995, pp. 518–523. <https://dl.acm.org/doi/10.5555/1625855.1625923>.

KEYWORDS: Condition-based maintenance; CBM; Internet of Things; IoT; neural network chips; wireless sensors; integrated processing; anomaly detection